NUREG/CP-0170

International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications: Summary of Planning Meeting

Held at
University of Maryland
College Park, MD 20742

October 25-26, 1999

Sponsored by
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Abstract

The U.S. Nuclear Regulatory Commission (U.S. NRC) convened a planning meeting with international experts and practitioners of fire models to discuss a potential international collaborative project to evaluate fire models for nuclear power plant applications. The meeting was jointly organized with the Society of Fire Protection Engineers and the University of Maryland and was held at the University of Maryland on October 25 - 26, 1999. Thirty representatives from eight national organizations in the United States and six international organizations from five countries attended the planning meeting. The attendees represented organizations in the nuclear industry and built environment in several countries that are involved in the development and use of fire models.

All organizations represented responded positively to NRC's invitation for a collaborative effort. Representatives indicated they intended to participate and contribute to the project with the goal of obtaining results of mutual benefit to their respective organizations. Participants plan to contribute through a variety of means. The core of the work will be conducted by six nuclear organizations in France, Germany, Finland, and the United States. The initial effort will consist of analyzing a specific issue, safe separation distance between redundant trains in nuclear power plants, to evaluate how current state-of-the-art fire models can be used to support decision making regarding this issue in nuclear power plants. A guidance/reference document oriented toward "low end" users on the use of current fire models will be the initial product of the project. After several issues are evaluated and the current state of the art of fire models better defined, a second phase of the project could be initiated to improve fire modeling and tools in order to support their extended use for fire safety design and decision making in nuclear power plants.

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1 Introduction

The U.S. Nuclear Regulatory Commission (U.S. NRC) convened a planning meeting with international experts and practitioners of fire models to discuss a potential international collaborative project to evaluate fire models for nuclear power plant applications. The planning meeting was hosted jointly with the Society of Fire Protection Engineers (SFPE), and the University of Maryland (UMD), and was held at the University of Maryland in College Park, Maryland, USA on October 25, and 26, 1999. The Organizing Committee for the meeting included Moni Dey and Nathan Siu from the U.S. NRC, Brian Meacham from SFPE, and Fred Mowrer from UMD. The attendees of the meeting are listed in Attachment A.

The purpose of the planning meeting was to discuss the objective and scope of the proposed International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications. The scope of the project was proposed to range from a series of international meetings to exchange technical information on the subject, to a more organized project with established objectives and tasks. Other interested parties were requested to host future meetings of the project. One major purpose of the planning meeting was to discuss the extent to which parties are interested in participating in the project. It was suggested that parties could participate as experts to discuss specific issues and reviewers of project results, and/or conduct certain tasks in the collaborative effort.

The following discussion items were included in the agenda of the planning meeting:

I. Define problem (How do participants want to use fire models, and what do they view are the technical issues for applying the models in this manner)

II. Provide briefings on ongoing international activities/workshops that could have relevance to the issues for this project

III. Discuss the defined problem, and approaches to address the issues

IV. Discuss scope of project, and manner in which parties would like to participate

V. Develop project plan, and framework for future meetings

The full agenda of the meeting is included in Attachment B. A white paper outlining a proposed framework for the project (see Attachment C) was sent to participants to serve as a starting point for discussions at the meeting.

2 Meeting Summary

2.1 Session 1: Fire Model Needs and Applications in Nuclear Power Plants

The objectives of the 1st session on fire model needs and applications in nuclear power plants were to:

- Present the meeting agenda and NRC's interests and proposal for the project

- Provide a presentation comparing how fire models are used in the built environment versus NPPs toward two objectives: 1. Participants who are only familiar with one industry may gain some knowledge of how fire models are used in the other industry; and 2. Highlight commonalities and differences between fire model applications in the two industries, and therefore the requirements for the models. The objective of this presentation was to try to provide a common knowledge base to all participants in order to facilitate common understanding and dialogue.

- Provide: (1) brief descriptions of how various organizations in the nuclear industries in various countries have used fire models to date, and their experience with the models (what do they believe are the technical issues), (2) the needs of the organization for fire modeling, and (3) their proposal for the collaborative project

- Present summary of Post-SMIRT Fire Model Workshop held in September 1999

The main desired outcomes of the session were to:

1. List needs for fire modeling identified by organizations
2. List experience and technical issues identified by speakers
3. List specific proposals for this project from organizations

The viewgraphs used for the presentations are included in Attachment D. The major points that were made by participants and recorded (on a flip chart) at the session are presented below followed by a summary of the discussion.

2.1.1 Fire Models for NPPs vs Built Environment

Points made by Participants

1. The nuclear industry has an established fire events data collection system which can be used to learn from fire experiences, whereas the built environment lacks a comparable data system.
2. The concerns of the built environment are tenability and life safety, whereas the thermal effects on equipment is the main issue for the nuclear industry.
3. Ignition sources are different in the two industries.
4. The basic principles of fire phenomena are the same for both industries. Research at the basic level should be equally valuable to both industries.
5. Since uncertainties are tied to decision making, the importance of the limitations of models will vary based on the industry and the manner in which they are used.
6. Ceiling obstructions in nuclear plants pose a specific challenge to models.
7. The fire loads in nuclear power plants are more fixed and predictable.
8. It will be useful to further define the similarities and differences between the built environment and the nuclear industry.

Summary of Discussion

The nuclear industry has several advantages over the built environment for the implementation of fire modeling, e.g. a fire events data system, and more fixed and predictable fire loads. Although ignition sources and the safety objectives of the two industries are different (i.e. tenability and life safety versus thermal effects on equipment), the basic principles of fire phenomena are the same for both industries. Research at the basic level should be equally valuable to both industries. However, since uncertainties are tied to decision making, the importance of the limitations of models will vary based on the industry and the manner in which they are used. The similarities and differences between the built environment and the nuclear industry should be further defined to identify specific areas for collaboration.

2.1.2 Fire Modeling Needs

Points made by Participants

1. Support fire protection program change analysis per Regulatory Guide 1.174 (NRC).
2. Conduct plant probabilistic risk analysis and determine contribution of fire to plant risk (NRC).
3. Examine plant fire protection alternatives, e.g. evaluate suppression versus ventilation for smoke control in turbine building fires, and determining acceptable levels of combustible materials in a fire area (Duke-Energy).

4. Make available simple, usable, <u>and</u> acceptable (to regulator) models for specific applications (NEI).
5. Provide training to "low end[1]" plant users on the basics and applications of fire models (Duke-Energy).
6. Define risk-informed applications by surveying nuclear power plant (NPP) staff (EPRI).
7. Provide guidance to the end user on the use of models for specific NPP fire scenarios (EPRI).
8. Analyze safe separation distance of redundant shutdown trains (EdF).
9. Analyze fire protection licensing issues, e.g. barrier ratings, accident analyses (GRS).
10. Uncertainties of models needs to be minimized (GRS).

<u>Summary of Discussion</u>

The foremost need is to develop and define guidance for "low end" users on the validity and limitations (or uncertainties) of fire models for specific applications. Simple, usable, <u>and</u> acceptable (to regulator) models for specific applications need to be made available. Examples of fire modeling applications are examination of safe separation distance of redundant safety trains and fire barrier ratings, evaluation of suppression versus ventilation for smoke control in turbine building fires, and determination of acceptable levels of combustible material in a fire area.

2.1.3 Fire Modeling Issues

<u>Points Made by Participants</u>

1. Strengths and weaknesses have not been fully evaluated (NRC).
2. Lack of guidance for PRA analysts (NRC).
3. Lack of technology transfer from fire modeling research community to "low end" plant users (Duke-Energy).
4. Validity and conservatism need to be defined (EdF).
5. Benefits of using fire models needs to be better defined (EPRI).
6. Specific aspects of models need improvement, e.g. plume models, large fires, thermal stratifications (IPSN).
7. Data needs to be developed for input parameters such as the heat release rates, including feedback effects for fire growth (EdF).
8. Data needs to be developed for heat release rates, ignition point, and fire growth (GRS)

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[1]Personnel at nuclear plants that will analyze issues using fire models to support plant decisions on their fire protection programs.

Summary of Discussion

The strengths and weaknesses of fire models have not been systematically evaluated, and currently there is a lack of technology transfer from the fire modeling research community to "low end" plant users. The validity, limitations, and conservatism of the current state-of-the-art fire models, including the benefits that can be derived from them, need to be defined. Specific aspects of fire models need improvement, e.g., plume models, application for large fires, thermal stratifications, and feedback from fires. Data needs to be developed for input parameters such as the heat release rates, and ignition point.

2.1.4 Proposals for Project

Points Made by Participants

1. Evaluate validity and limitations of models by analyzing standard problems (NRC).
2. Develop guidance for PRA analysts (NRC)
3. Develop a user's manual (best practice document) for "low end" plant users (Duke-Energy).
4. Evaluate validity and limitations of models by defining and examining specific applications and scenarios (EPRI).
5. Validate a set of models by comparison with experiments, and challenging fires (GRS)
6. Develop guidance on use of fire models for specific NPP applications (EPRI, EdF, GRS)
7. Develop a pilot project (for a specific plant) for evaluating fire models (EPRI).
8. Define experimental validation tests, where necessary, that best supplement the need, i.e., typical NPP fire scenarios (EPRI).
9. Benchmark fire models against fire events and typical NPP fire scenarios (EPRI).
10. Extend range of validity of models, improve plume models, and capability of models for fires in large compartments (IPSN).
11. Develop guidance for scenario development, input parameters, and assumptions notably for electrical cabinets and cable fires (IPSN, EdF).
12. Analyze safe separation distance of redundant shutdown trains (EdF)
13. Validate fire models (EdF).
14. Develop guidance for using fire models for fire protection program design applications and assessment (EdF).
15. Create a forum for exchange of technical information, and joint research activities (GRS).
16. Harmonize various fire models by comparison with experiments and common data, e.g. for cable fires (GRS).

17. Investigate specific issues such as burning rate, and ignition point (GRS).
18. Provide means for cross-participation in national projects (GRS).
19. Identify national point of contact for project (GRS).

<u>Summary of Discussion</u>

The validity and limitations of fire models should be evaluated by defining and examining specific applications and scenarios (standard problems). The applications should be related to the design and assessment of fire protection programs, and the guidance should be developed for "low end" users. The guidance should be in the form of a user's manual that would serve as a reference and best practice document for users of fire models for specific applications. The user's manual should include guidance on scenario development, and the selection of input parameters and assumptions. Safe separation distance of redundant shutdown trains is a good candidate for a specific application of fire models. Specific attention should be given to fires involving electrical cabinets and cables.

Experimental validation tests should be defined, where necessary, that best supplement the need, i.e., NPP fire scenarios for specific applications. The range of validity of models should be extended, e.g., by improving plume models and the capability of models for fires in large compartments, and developing data for heat release rates and ignition points. The fire models should be benchmarked against fire events for typical NPP fire scenarios.

2.2 Session 2: Lessons Learned from Activities in Built Environment

The objectives of the second session on lessons learned from activities in the built environment were to:

- Provide brief descriptions of ongoing international activities that may have relevance to the project

- Present the technical and programmatic issues faced by the activities, and "lessons learned" from them

- Determine if these technical and programmatic issues, and "lessons learned" apply to NPPs

The desired outcomes of the session were to:

1. List technical and programmatic issues faced that apply to NPPs

2. List "lessons learned" from activities that are relevant to NPPs

The viewgraphs used for the presentations are included in Attachment D. The major points that were made by participants and recorded (on a flip chart) at the session are presented below followed by a summary of the discussion.

2.2.1 Lessons Learned

1. Quality of data is key to the successful evaluation of fire models.
2. Significant resources are required in the evaluation of fire models.
3. Voluntary collaborative evaluations can require significant periods.
4. The chance of success in a collaborative evaluation effort is increased if the cases studied are simple and well understood in advance.
5. Users of fire models should have some basic understanding of fire dynamics.
6. Most of the variables can be predicted at least by a factor of two (many of them much better).
7. Simulations could be improved by choosing alternate submodels and/or changing optional parameters.
8. CFD models have several advantages over zone models, but they need qualified users and good user's guidance.
9. The quality and usefulness of experimental data can be enhanced if the experiments and computer simulations are conducted in parallel. The nature of the data required can be better defined based on simulation trials.
10. Next generation instrumentation is needed for proper CFD verification.
11. Experiments should be carefully designed to meet established objectives.
12. Experimental data may have errors and should be evaluated for accuracy.
13. Verification and validation are terms that have different meanings to different people. Definitions of the terms should be developed and agreed upon.
14. There is variability in the results from various codes, and from different users of the same code.

2.2.2 Open Issues

1. Data sources need to be identified.
2. Commitments should be made to the resources needed for the evaluations.
3. The problem and the procedure for the evaluation needs to be well defined.
4. Reference cases (for standard problems) need to be developed.
5. The initial test case should be simple.
6. Users of fire models need to be trained in fire dynamics.
7. The spread of fire, and fully developed fires need more research and understanding.
8. Issues related to a computer code and its usage should be separated and understood.

9. The limitations and shortcomings of fire models, based on the physics handled by the models, need to be identified.
10. Blind simulations are needed to provide confidence in the use of the codes.
11. Education, and "best practice" guides are needed.
12. NFPA "Regulatory Issues"
    - "acceptable" models
    - "qualified" users
    - "acceptance" criteria for models
    - uncertainty and reliability are key issues

2.2.3 Japanese Approach

- Performance standards couple design fire, fire scenarios, safety criteria and test methods.
- Design fires and scenarios are based on "acceptable" risk and cost.
- Acceptable risk is based in part on fire frequency, building height, floor area, and expected building life, and compared to that provided by current prescriptive regulations.
- Some fire problems can be analyzed with simple hand calculations, without the need for sophisticated computer codes (you don't need a Rolls Royce always).

2.2.4 Summary of Discussion

Significant resources are required for the evaluation of fire models, and voluntary collaborative evaluations can require significant time periods. The chance of success is increased if the cases studied are simple and well understood in advance. In order to achieve success, commitments should be made to the needed resources for the evaluations. Reference cases (for standard problems), and the procedure for the evaluation, needs to be well defined. Quality of data is key to the successful evaluation of fire models, and the data sources need to be identified. Verification and validation are terms that have different meanings to different people. Definitions of the terms should be developed and agreed upon before an evaluation effort.

Users of fire models should have some basic understanding of fire dynamics. Education, and "best practice" guides are needed. The limitations and shortcomings of fire models, based on the physics handled by the models, need to be identified. There may be variability in the results from various codes, and from different users of the same code. Issues related to a computer code and its usage should be separated and understood.

Most of the variables in fire models can be predicted at least by a factor of two (many of them much better). Simulations usually could have been improved by choosing alternate submodels and/or changing optional parameters. The quality and usefulness of experimental data can be enhanced if the experiments and computer simulations are conducted in parallel, and the data required is defined based on simulation trials. Experiments should be carefully designed to meet established objectives for validating models. Caution should be exercised in the comparison of experimental results with model results since experimental data may also have errors, and should be evaluated for accuracy. Blind simulations are needed to provide confidence in the use of the codes.

CFD models have several advantages over zone models, but they need qualified users and good user's guidance. Next generation instrumentation is needed for the proper verification of CFD models.

The Japanese effort has shown how performance standards can successfully couple a design fire, fire scenarios, safety criteria and test methods. Design fires and scenarios are based on "acceptable" risk, and cost. The "acceptable" risk is based in part on fire frequency, building height, floor area, and expected building life, and compared with that provided by existing prescriptive regulations. Some fire problems are analyzed with simple hand calculations, without the need for sophisticated computer codes.

2.3 Session 3: Summary and Discussion

The following summary of Session 1 was provided to facilitate planning of the project in Session 4.

2.3.1 Needs/Issues for Fire Modeling

1. Fire protection program design and change analysis.
2. Guidance document
    - acceptable
    - usable
    - oriented toward specific applications and scenarios
3. Training of users and technology transfer
4. Improvements to specific fire model features
    - plume models
    - heat release rates
    - Ignition point
    - Fire growth
    - Ventilation

2.3.2 Proposals

1. Develop guidance
    - oriented to "low end" users
    - oriented to specific applications and scenarios
    - identify limitations
    - applicable for program design and modifications
2. Define and evaluate fire models for specific applications and scenarios.
3. Improve and validate fire models

2.4 Session 4: Project Planning

The objectives of the 4th session on project planning were to:

- Achieve agreement among participants on the technical scope for the project based on proposals presented and discussed on the previous day

- Discuss programmatic issues
    - How do participants want to contribute to project (peer review only or conducting tasks also)?
    - Is there a need for a formal agreement between parties?
    - Are there any potential proprietary or other issues?
    - How frequently do participants want to meet?
    - Determine near term plans (including date and location of next meeting)
    - Determine project interfaces to organizations/activities in built environment

- Discuss, on a preliminary basis, approaches to conduct agreed-upon tasks (e.g. if participants would like to pursue the *Standard Problem* approach, discuss protocol for this approach, and potential fire scenarios that participants may want to address)

The major points that were made by participants during the session and recorded (on a flip chart) at the session are presented below, followed by a summary of the outcome of the discussions.

2.4.1 Points Made by Participants

1. Elements of the project need to be developed.
2. Protocol for evaluating fire computer models need to be developed.
3. Definitions of validation and verification need to be developed.

4. Applications in which current fire models can be used should be defined as opportunities for near-term successes.
5. It is necessary to define the applications prior to developing the fire scenarios that need to be evaluated for that application.
6. It may be desirable to explore approaches for developing design fires, but that may be difficult.
7. Bounds of the capability of fire models to analyze scenarios need to be defined.
8. Elements of guidance/reference document
    - establish short-term goals and objectives
    - orient to "low end" users
    - provides guidance on acceptability of models for specific applications
    - evaluate capability of the state of the art
    - address specific applications
    - establish needs/use of document first
    - should provide a process users can go through to determine what can and cannot be done with models
    - should include guidance on which models are suitable for which applications
    - should provide guidance on input parameters for the models
9. Development of applications and scenarios
    - safe separation distance is a good candidate for evaluation
    - thermal barriers (for cable trays) is also a good candidate for evaluation
    - determining the adequacy of detection and suppression systems is a good practical and useful area for evaluation
    - the problem needs to be clearly defined prior to developing the application and scenarios
    - In defining examples and scenarios, investigate what has and has not been done first
    - evaluate capability and limitations of the state-of-the-art-models
    - develop guidance for end users
    - determine which problems need to be solved first
10. Examples of problems that need to be solved
    - adequacy of smoke detectors
    - limits on transient combustible sources
    - safe separation distance
11. Task group should established to define needs and problems
12. Evaluation of safe separation distance
    - capability to simulate target response, which is a common phenomena that needs to be investigated for other issues such as effectiveness of thermal barriers, will be included in this evaluation
    - limitations and uncertainties should be defined

- various computer codes should be exercised in this evaluation
- divide evaluation into (1) sources, (2) exposure conditions, and (3) target response

13. Near term goals
    - develop goals and objectives of guidance/reference document
    - formulate scenarios for evaluation of safe separation distance
    - establish U.S. task group for defining other problems of interest in the U.S.
    - compile information (data, model features/capabilities) for evaluation of safe separation distance prior to next meeting
14. Interface with Built Environment
    - Participants in this project are invited as observers to CIB W14 meetings (next meeting is on June 14, 1999)
    - Participants may attend ISO TC 92 SC 4 working group meetings, however attendance at Technical Committee meetings may be limited (requests should be made through SFPE)
    - SFPE working group meetings are open to the group (see web site for meeting announcements)
    - requests may be forwarded to the Large Scale Disaster Institute in Japan regarding information on specific modeling issues
15. Other interfaces identified
    - NFPA 805 standard development effort for NPPs
    - OECD-PWG 5 working group on fire risk analysis
16. Meeting report
    - summary of meeting
    - project plan
    - issue to participants for comments
    - include list of action items
17. Future meetings
    - Meeting No. 2 - Hosted by IPSN in Fontenay-aux-Roses, France on June 19, 20, 2000
    - Meeting No. 3 - Hosted by EPRI in Palo Alto, California, USA (suggested date is before or after United Engineering Foundation meeting meeting on January 7-12, 2001 in San Diego)
    - Meeting No. 3 - Hosted by GRS in Germany

2.4.2 Outcome of Discussion

Technical Scope

The protocol for evaluating models should be developed, and terms such as validation and verification need to be defined. The evaluation should be application oriented, and applications should be chosen for near-term successes. The problem being solved needs to clearly defined prior to developing the application and scenarios. A review of any previous work on the issue being investigated should be conducted as part of the evaluation.

Product from Project

A guidance/reference document oriented toward "low end" users should be the initial and primary product of the project. The elements of the guidance/reference document should be developed. A preliminary list of the elements of the guidance/reference document follows:

- goals and objectives of document
- manner in which the document should be used
- a process users can go through to determine what can and cannot be done with models
- acceptability of models for specific applications
- capability of the state-of-the-art models to analyze specific scenarios
- suitability of models for different applications
- appropriate input parameters and assumptions
- limitations and uncertainties

Initial Application for Evaluation

The application of fire models to examine the safe separation distance between redundant shutdown trains is a good candidate for the initial task of the project. The capability to simulate target response, which is a common phenomena that needs to be investigated for other issues such as effectiveness of thermal barriers, will be included in the evaluation of safe separation distance. Various computer codes should be exercised in this evaluation, and the evaluation should be divided into (1) sources, (2) exposure conditions, and (3) target response. Information on data, model features and capabilities should be compiled. Scenarios should be formulated for the evaluation of safe separation distance prior to the next meeting.

Potential Future Applications

Determining the adequacy of detection and suppression systems, and limits on transient combustible sources are good practical and useful areas for evaluation. Effectiveness of thermal barriers (for cable trays) is also a good candidate for evaluation.

U.S. Task Group

A U.S. task group should be established to define other needs and problems of interest in the U.S. nuclear industry.

Interface with Built Environment

Participants in this project are invited as observers to CIB W14 meetings (next meeting is on June 14, 2001). Participants may attend ISO TC 92 SC 4 working group meetings, however attendance at Technical Committee meetings may be limited. Requests should be made through SFPE. The SFPE working group meetings are open to the group (see web site for meeting announcements). Requests may be forwarded to the Large Scale Disaster Institute in Japan regarding information on specific modeling issues.

Other Interfaces

The project should establish an interface with the NFPA 805 performance-based standard development effort for NPPs, and the OECD-PWG 5 working group on fire risk analysis.

Meeting Report

A summary of the meeting and project plan will be prepared and issued to participants for comments. The project plan should include a list of action items.

Future Meetings

The second meeting of the project will be hosted by IPSN in Fontenay-aux-Roses, France on June 19, 20, 2000. The 3rd meeting will be hosted by EPRI in Palo Alto, California, USA (suggested date is before or after the United Engineering Foundation meeting on January 7-12, 2001 in San Diego). The 4th meeting will be hosted by GRS in Germany in September 2001.

Attachment A: List of Attendees

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Attachment B: Agenda

Planning Meeting for Proposed International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications

October 25-26, 1999

Organizing Committee

M. Dey, N. Siu, U.S. Nuclear Regulatory Commission
B. Meacham, Society of Fire Protection Engineers
F. Mowrer, University of Maryland

Objective

The objective of this meeting is to plan the proposed collaborative project. In the future (probably at the next meeting), it will be beneficial to have a workshop that includes sufficient time to exchange technical information and learn about each another's research programs. At this meeting, we suggest only brief presentations of past or ongoing research efforts in our respective organizations that are pertinent to identifying technical issues for planning this project.

Format

The meeting will be conducted in an informal format. Time periods have been allotted for various presentations. To facilitate dialogue, participants are encouraged to ask questions and engage in discussions during the prepared remarks. Therefore, speakers are requested to prepare remarks that would take no more than 15 minutes to present, if uninterrupted.

Each session will have a Discussion Leader(s) who will guide the briefings by presenters, and lead discussions during and after prepared remarks are presented. After each presentation, the Discussion Leader(s) will list the main points from the prepared remarks on flip charts. These lists will be used later in presentations of session summaries, and for project planning.

Registration/Opening

8:00-8:30 am	Registration	
8:30-8:35 am	Fred Mowrer, UMD, USA	Welcome/Introductions

Session 1: Fire Model Needs and Applications in Nuclear Power Plants
October 25, 1999, 8:35am - 12:30 p.m.
Discussion Leader, M. Dey

<u>Objectives of Session</u>

- Present meeting agenda and NRC's interests and proposal for project (Dey)
- Provide a presentation comparing how fire models are used in the built environment versus NPPs so that: 1. Participants who are only familiar with one industry gain some knowledge of how fire models are used in the other industry; 2. Highlight commonalities and differences between fire model applications in the two industries, and therefore the requirements for the models (Mowrer). The objective of this presentation is to try to provide a common knowledge base to all participants in order to facilitate common understanding and dialogue.
- Provide: (1) brief descriptions of how various organizations in the nuclear industries in various countries have used fire models to date and their experience with the models (what do they believe are the technical issues), (2) the needs of the organization for fire modeling, and (3) their proposal for the collaborative project (Brandes, Kassawara, Bertrand, Kaercher, Roewekamp)
- Present summary of Post-SMIRT Fire Model Workshop held in September 1999 (Roewekamp)

Session 1: Fire Model Needs and Applications in Nuclear Power Plants

8:35-9:00 am	M. Dey, *NRC*, USA	Meeting Agenda/NRC's Proposal for Project
9:00-9:25 am	F. Mowrer, *UMD*, USA	Fire Models for NPPs vs Built Environment
9:25-10:00 am	D. Brandes, *Duke-Energy*, USA F. Emerson, *NEI*, USA	US Nuclear Industry User Perspective
10:00-10:15 am	Break	
10:15-11:55[2] am	1. R. Kassawara, *EPRI*, USA 2. R. Bertrand, *IPSN*, France 3. M. Kaercher, *EdF*, France 4. M. Roewekamp, *GRS*, Germany	Summary of Experience, Needs, and Proposal for Project from Respective Organizations
11:55 am-12:10 p.m.	M. Roewekamp, *GRS*, Germany	Summary of Post-SMIRT Workshop
12:10 p.m. - 1:30 p.m.	Lunch[3]	

Desired Session Outcomes

1. List needs for fire modeling identified by organizations
2. List experience and technical issues identified by speakers
3. List specific proposals for this project from organizations

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[2]Fifteen minutes has been allotted for each presentation, and ten minutes for group discussion on the presenter's prepared remarks.

[3]Lunch at the *Rossborough Inn* in the UMD campus, and coffee breaks are provided courtesy of the University of Maryland

Session 2: Lessons Learned from Activities in Built Environment
October 25, 1999, 1:30 - 4:00 p.m.
Discussion Leader, B. Meacham

Objectives of Session

- Provide brief descriptions of ongoing international activities that may have relevance to project
- Present the technical and programmatic issues faced by the activities, and "lessons learned"
- Determine if these technical and programmatic issues, and "lessons learned" apply to NPPs

1:30-1:55 p.m.	M. Hurley, *SFPE*, USA	Potential Usefulness of SFPE Activities to Project
1:55-2:20 p.m.	M. Kokkala, *VTT*, Finland	Potential Usefulness of CIB W14 Evaluation to Project
2:20-2:45 p.m.	G. Cox, *Building Research*, UK	Potential Usefulness of ISO/ TC92 Activities to Project
2:45-3:10 p.m.	D. Beller, *NFPA*, USA	NFPA Performance Initiatives
3:10-3:30 p.m.	Break	
3:30-4:00 p.m.	T. Tanaka, *BRI*, Japan	Experience with Japanese Performance-Based Building Code

Desired Session Outcomes

1. List technical and programmatic issues faced that apply to NPPs
2. List "lessons learned" from activities that are relevant to NPPs

Session 3: Summary and Discussion
October 25, 1999, 4:00-5:00 p.m.

4:00-4:30 p.m.	M. Dey	Summary of Needs, Technical Issues, and Proposals for Collaborative Project
4:30-5:00 p.m.	B. Meacham	Summary of Issues and "Lessons Learned" from Activities in Built Environment

No-Host Dinner 6 p.m.

94th Aerosquadron
College Park

Session 4: Project Planning
October 26, 1999, 8:30 am - 12 Noon
Discussion Leaders, F. Mowrer, M. Dey.

Objectives of Session

- Achieve agreement among participants on the technical scope for the project based on proposals presented and discussed on previous day

- Discuss programmatic issues
  - How do participants want to contribute to project (peer review only or conducting tasks also)?
  - Is there a need for a formal agreement between parties?
  - Are there any potential proprietary or other issues?
  - How frequently do participants want to meet?
  - Determine near term plans (including date and location of next meeting)
  - Determine project interfaces to organizations/activities in built environment

- Discuss, on a preliminary basis, approaches to conduct agreed-upon tasks (e.g. if participants would like to pursue the *Standard Problem* approach, discuss protocol for this approach, and potential fire scenarios that participants may want to address)

8:30-8:45 am	M. Dey	Proposed Technical Scope for Project Based on Previous Day's Discussions
8:45-9:30 am	All	Discussion
9:30-9:45 am	M. Dey	Proposed Program Plan Based on Previous Day's Discussions
9:45-10:15 am	All	Discussion
10:15-10:30 am	Break	
10:30-11:45 am	F. Mowrer + All	Preliminary Discussion on Approaches to Conduct Agreed-Upon Tasks
11:45 am-12 Noon	M. Dey	Near term plans (including date and location of next meeting)
12 Noon	F. Mowrer	Closing Remarks

Attachment C: White Paper

Proposed International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications

Paper for Discussion[4] at Planning Meeting on October 25-26, 1999

Background

Risk-informed and performance-based approaches to fire regulation in nuclear power plants requires the use of computer models and analytic methods to predict a wide range of fire conditions. In traditional prescriptive regulations, fire protection system configurations are specified based on engineering judgment derived from operating experience, tests, and codes and standards. In a performance-based regulatory system, the fundamental premise is that the performance of the fire safety systems can be predicted under various fire conditions. This gives fire protection system designers greater flexibility to implement cost-effective systems and the ability to determine the safety levels achieved by their designs. The primary tools for predicting the performance of fire safety systems, as well as for predicting the development and spread of fire, are computer models and analytic methods of varying degrees of complexity.

Objective

The objective of the proposed collaborative effort is to create a forum to share the knowledge and resources of various organizations to improve the state of the fire modeling methods and tools for use in nuclear power plant fire safety.

The NRC proposes a two-phase project. The objective of the first phase of the proposed collaborative project is to evaluate how current state-of-the-art fire models can be used to support decision making for fire safety in nuclear power plants. Specifically, fire models will be evaluated to determine whether they can provide valid information for decision making. A second phase of the project could be initiated, once the limitations of the current state of the art are defined, to improve fire modeling methods and tools in order to support their extended use for fire safety design and decision making in nuclear power plants.

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[4]This paper has been written mostly to meet the needs of the USNRC, and the US nuclear industry. It is intended to serve as a starting point for discussions at the meeting to incorporate the needs of other parties participating in the meeting.

Scope and Framework

Fire models may be used in deterministic or probabilistic assessments to support fire safety design (including operational aspects such as control of combustibles). The requirements and the applicability of fire models will vary with their intended use. A categorization of their applications follow:

II. Deterministic assessments.

In deterministic assessments, fire models may be used to:

(i) compare fire safety design alternatives (e.g. different combinations of separation, suppression, and passive protection of equipment), or
(ii) determine if a particular fire protection system configuration in a fire area meets acceptance criteria for a design fire scenario.

2. Probabilistic Assessments.

Probabilistic assessments, that incorporate results from fire model analyses, may be used to determine:

1. weaknesses in plant fire safety designs, or the relative merits of alternative design approaches (requires estimate of *relative risk*), or
2. the *absolute risk* contribution from a particular fire scenario or area (e.g. for determining if additional protection is needed to address a specific weakness).

Since the NRC is transitioning to a risk-informed, performance-based regulatory framework (NRC, 1999), the NRC proposes that fire models be evaluated in this project mainly in the context of their use with probabilistic risk assessment methodology. However, fire models can also be assessed as a tool to evaluate and compare performance, e.g. to determine whether a barrier provides the protection necessary within an acceptable margin or which alternative design provides the best protection at lowest cost.

Phase I

The NRC proposes that the first phase of the collaborative project be aimed at evaluating how current state-of-the-art fire models can be used to support risk-informed, performance-based decisions for fire safety in nuclear power plants (NRC, 1998). This can be best accomplished by choosing a few scenarios and applications, and investigating the validity and limitations of fire models to support *specific* decisions.

A schematic of the proposed process to evaluate fire models for decision making is shown in the attached Figure. The first step in this process is to define the manner in which users would like to employ fire models for nuclear power applications. This is an essential and critical step since the requirements of fire models will vary with their application. Fire models that provide conservative bounding results may suffice for comparing fire safety features, and for determining weaknesses in designs; whereas, best estimate models may be required to support safety decisions that are based on the contribution of fire risk to total risk from all other threats to plant safety. Once the applications are established, fire scenarios can then be developed for those applications.

The second step in the project would be to determine how current fire models can be used to support the specific application and safety decision. This assessment will result in a number of technical issues which will need further investigation. These issues should be examined to determine the validity and limitations of the fire models to support the decision making. Applicability of the models to support safety decisions, and areas of improvement are outcomes of the process.

The following are two potential applications[5] and scenarios to support plant change analysis that could be investigated in the project:

I. Safe separation distance: Examine the validity of fire models to support plant changes to safe separation distance of redundant cable trays (transient liquid fire source) based on calculation of time to damage and change in core damage frequency.

   NRC fire protection regulations require that one train of systems necessary to achieve and maintain hot-shutdown conditions be free of fire damage. The regulation provides three options for meeting this requirement, including one that allows for separation of cables, equipment, and associated non-safety circuits of redundant safe-shutdown trains by a horizontal distance of more than 6.1 m (20 ft) with no intervening combustible materials or fire hazards. In addition, fire detectors and an automatic suppression system must be installed. In some instances, nuclear plants may wish to change equipment configurations and locations. This *case study* would involve examining the validity of fire models to support plant changes to safe separation distance of redundant cable trays in a typical nuclear power plant configuration.

II. Fire barriers: Examine the validity of fire models to support derating of fire barriers in a electrical cabinet fire scenario based on calculation of change in core damage frequency.

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[5]These applications are provided to serve as a starting point for discussions. Other parties participating in the meeting are encouraged to propose applications.

Another option provided by NRC's regulations to protect one train from fire damage is by separation of redundant trains with a fire barrier with a 3-hour rating, or a 1-hour rating with the installation of fire detectors and an automatic suppression system in the fire area. This *case study* would involve examining the validity of fire models to support fire protection systems design that use less than the prescribed fire barrier ratings, and different combinations of fire barriers, detectors, and automatic suppression to protect one redundant train from fire damage.

The investigation of these applications will entail analyses of specific fire scenarios with current fire models. Participants in the project may conduct analyses for these *standard problems* with computer codes available in their respective organizations (e.g. CFAST, COMPBRN, FLAMME-S, MAGIC, and LES) to examine code capabilities and evaluate validity of the codes to support safety decisions. The examination of the validity of the codes would include comparison of model outputs to experimental data. The availability and quality of data for such comparisons is a key issue to be discussed. The comparison and examination of results from different models will provide insights regarding the effects of the differences in the data and correlations used in the models on the results. A protocol will need to be developed and used for the approach to the computations and comparisons to yield relatively unbiased results. This task can draw from work already done by participants, but will probably entail new work. The results of these assessments will define the validity of current models for a variety of fire applications and scenarios. The limitations of the models, and potential areas of improvement for the extended use of fire models in fire safety design will also be identified.

Presently, fire models are engineering tools, with limitations and constraints. It may not be possible to completely "validate" a model by defining the limitations of the model, and the bounds within which results from the model are valid. Different engineers will probably get different results from the same fire model. Therefore, it is essential that the model user has a thorough understanding of the model's strengths and weaknesses. The education and training of model users and reviewers will be critical to the successful use of performance-based models and should be addressed in this project.

A consensus report can be developed by participants at the end of the first phase of the proposed collaborative project to document the results of the project.

Near Term Related NRC Task

In parallel to the above task the NRC proposes for the collaborative program, it will be conducting a similar task to meet its near term commitments. In order to inform fire PRA analysts (many of whom are not experts in fire sciences and modeling) involved in

PRA studies, the NRC will develop guidance on the uncertainties and limitations of fire models for a broad spectrum of fire scenarios analyzed *generally* in fire PRAs (without specific consideration of the applications of the results). Since the results of this task may be of interest to participants in this collaborative project, the NRC will present an outline of this task at the upcoming planning meeting, and the results at a future meeting of the project. The NRC will welcome any comments and contributions that participants may wish to provide to this near term task that is scheduled to be completed by September 2000 to meet NRC's program goals.

All participants are encouraged to present any past, present and planned research activities in their organizations that may contribute to the objectives of this proposed collaborative program.

Phase II

The second phase of the project could be initiated to improve fire modeling methods in order to support their extended use for regulatory decision making in nuclear power plants.

This phase would go beyond a review and assessment of current technology, and entail research activities to improve models, including tests to support their development and validation.

A decision on initiating Phase II will be made upon completion of Phase I. The tasks in Phase II will be formulated and prioritized based on the results of Phase 1.

Coordination with International Activities in the Built Environment

A number of activities in the built environment are currently underway to evaluate and validate fire models, e.g. CIB W14, ISO, and the SFPE efforts. This project will utilize the approaches and technical information from these efforts, to the extent applicable, for the review and assessment conducted in Phase 1.

Although the primary focus of this project is on enclosures typical to nuclear power plants, it is expected that the outcomes of the first phase and any follow up work in the second phase will be pertinent to a wide variety of applications.

Benefits of Collaborative Efforts

A collaborative project in this emerging technology has several benefits. Firstly, a collaborative program will allow a continual exchange of technical information between parties engaged in similar research tasks, as opposed to the more limited and less frequent exchange of information at major international seminars or symposia.

Collaborative efforts should result in decreased research costs for each party, especially if research includes more costly tasks such as experiments. Costly research tasks which may be prohibitively expensive to one organization, could be affordable in a collaborative effort.

The NRC, as many other organizations, seeks peer review and credibility of its research results, particularly in emerging technologies such as fire modeling. This collaborative projects will provide international endorsement and credibility to research conclusions that support decisions in an emerging regulatory framework for fire protection.

Participation

Participants to this collaborative effort are encouraged to:

- Discuss related research activities at their organization: past, present and future
- Provide expert review and feedback on research activities at other organizations
- Explore opportunities for collaborative research by pooling resources

Participants may serve as experts to discuss specific issues, and review project results. Participants may also choose to volunteer to conduct specific tasks (e.g. case studies) identified in the collaborative effort.

Meetings/Milestones

The NRC proposes that meetings will be held semi-annually to discuss project progress, specific issues, and results. In order to share the burden and cost of holding the meetings, the NRC proposes participants rotate in hosting the meetings. The meetings should mainly be limited to participants, but may be opened on specific occasions to a broader audience to benefit from feedback from diverse sources.

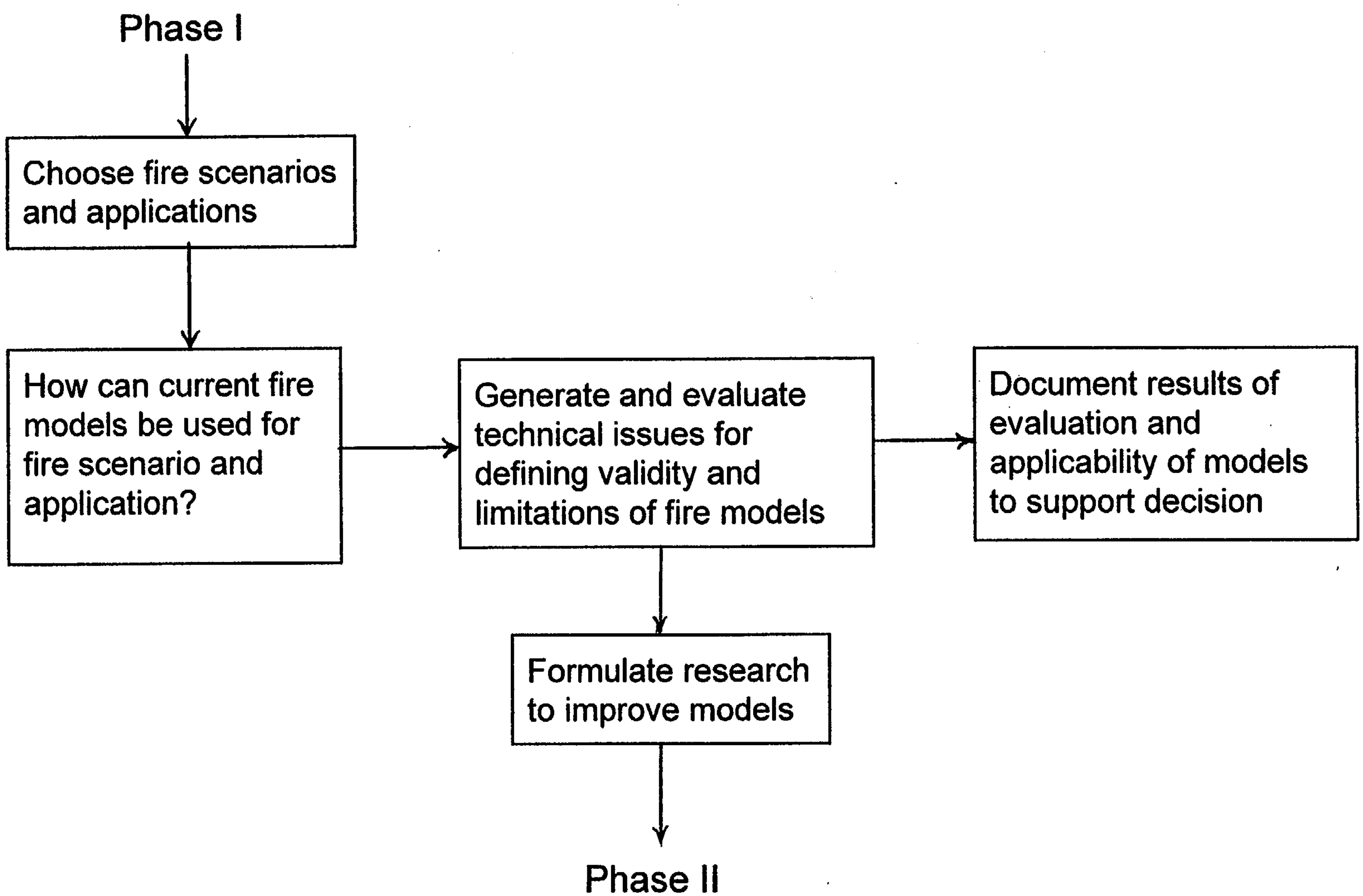
Milestones for the project will be established at the planning meeting on October 25-26, 1999.

References

U. S. Nuclear Regulatory Commission, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis", Regulatory Guide 1.174, July 1998.

U. S. Nuclear Regulatory Commission, "Commission Issuance of White Paper on Risk-Informed and Performance-Based Regulation," Memorandum to All Employees, Announcement No. 019, March 11, 1999.

Process to Evaluate Fire Models for Regulatory Decision Making



Attachment D: Viewgraphs Used for Presentations

Fire Models for NPPs vs Built Environment

F. Mowrer
Fire Protection Engineering
University of Maryland

Hierarchy

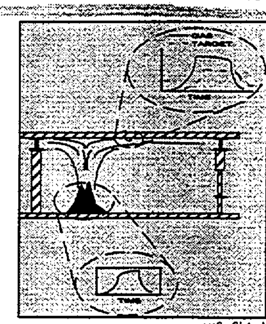
- Framework
  - Goals / objectives - needed calculations?
- Methodologies
  - Deterministic / probabilistic calculations
  - Error / uncertainty calculations
- Data
  - Models / parameters
  - Statistical

Issues

- Given a fire initiation in a building:
  - How will the fire develop?
    - What is the first item burning?
    - Will secondary fuels ignite?
    - Will flashover occur?
  - When will the fire be detected? suppressed?
  - Where will the smoke spread?
  - Will people / targets be injured / damaged?

Fire modeling concepts

- Fire source
  - HRR as f(t)
- Transport path
  - Barriers
- Target
  - T_{gas} as f(t)
  - T_{tar} as f(t)

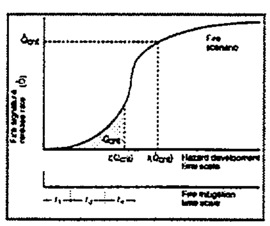


nrc2 - Slide 4

Fire modeling concepts

- Time scales
  - Hazard development
    - t_{crit}
  - Mitigation
    - $t_{transport}$
    - $t_{detection}$
    - $t_{suppression}$
- Objective

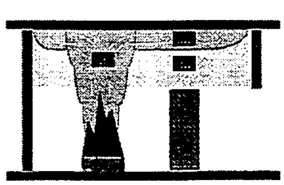
$$t_{crit} >> t_{tran} + t_{det} + t_{sup}$$



nrc2 - Slide 5

Elements of enclosure fires

- Fire source
- Fire plume
- Ceiling jet
- Upper gas layer
- Lower gas layer
- Vents / ventilation
- Boundaries
- Targets



nrc2 - Slide 6

Objectives

- Built environment
  - Life safety of occupants paramount
  - Property damage / mission continuity not generally addressed
  - Demonstrate that "reasonable" level of safety achieved
- Nuclear power plants
  - Mission continuity paramount
  - Life safety of occupants not generally addressed
  - Demonstrate low risk of core damage due to fire

nrc2 - Slide 7

Applications

- Built environment
  - Scenario-based
  - Focus on tenability criteria (occupants)
- Nuclear power plants
  - Scenario-based
  - Focus on thermal effects (targets)

nrc2 - Slide 8

Questions

- Built environment
  - How are scenarios selected / screened?
    - Are all risk-significant scenarios considered?
    - What constitutes a "reasonable" level of safety?
  - How good are the modeling tools being used?
- Nuclear power plants
  - How are scenarios selected / screened?
    - Are all risk-significant scenarios considered?
    - What constitutes a "low risk" of core damage?
  - How good are the modeling tools being used?

nrc2 - Slide 9

Modeling tools - zone

- Built environment
  - ASET
  - DETACT
  - FAST
  - FPETool
- Nuclear power plants
  - COMPBURN
  - FAST
  - FIVE
  - MAGIC

nrc2 - Slide 10

Modeling tools - field

- Built environment
  - IFS / LES
  - Jasmine
  - Smartfire
  - SOFIE
  - StarCD
  - ?
  - ?
- Nuclear power plants
  - ?
  - ?
  - ?
  - ?
  - ?

nrc2 - Slide 11

Summary

- Modeling concepts are fundamentally similar for NPPs and built environment
  - Objectives may be different
- Scenario selection is critical to model use
  - Fire growth prediction vs specification
  - Are all risk-significant scenarios considered?
    - Can models handle all risk-significant scenarios?

nrc2 - Slide 12

Proposed International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications

Moni Dey
U.S. Nuclear Regulatory Commission

Planning Meeting

University of Maryland
October 25-26, 1999

Objective of Project

- To create a forum to share knowledge and resources of various organizations to evaluate and improve state of fire modeling methods and tools for use in nuclear power plant fire safety

Agenda for Meeting

- Objective of meeting
- Format to focus on planning
- Session 1: Establish needs, issues, and proposals from nuclear organizations
- Session 2: Obtain "lessons learned" applicable to nuclear industry from built environment
- Session 3: Formulate project plan and near-term milestones

Use of Fire Models to Support Risk-Informed Regulatory Decisions

Fire risk calculations with fire models can be used to determine:

- Weaknesses in plant fire safety designs, or the relative merits of alternative design approaches (requires estimate of *relative risk*)
- The *absolute risk* contribution from a particular fire scenario or area (e.g. turbine building)

Use of Fire Models to Support Risk-Informed Regulatory Decisions

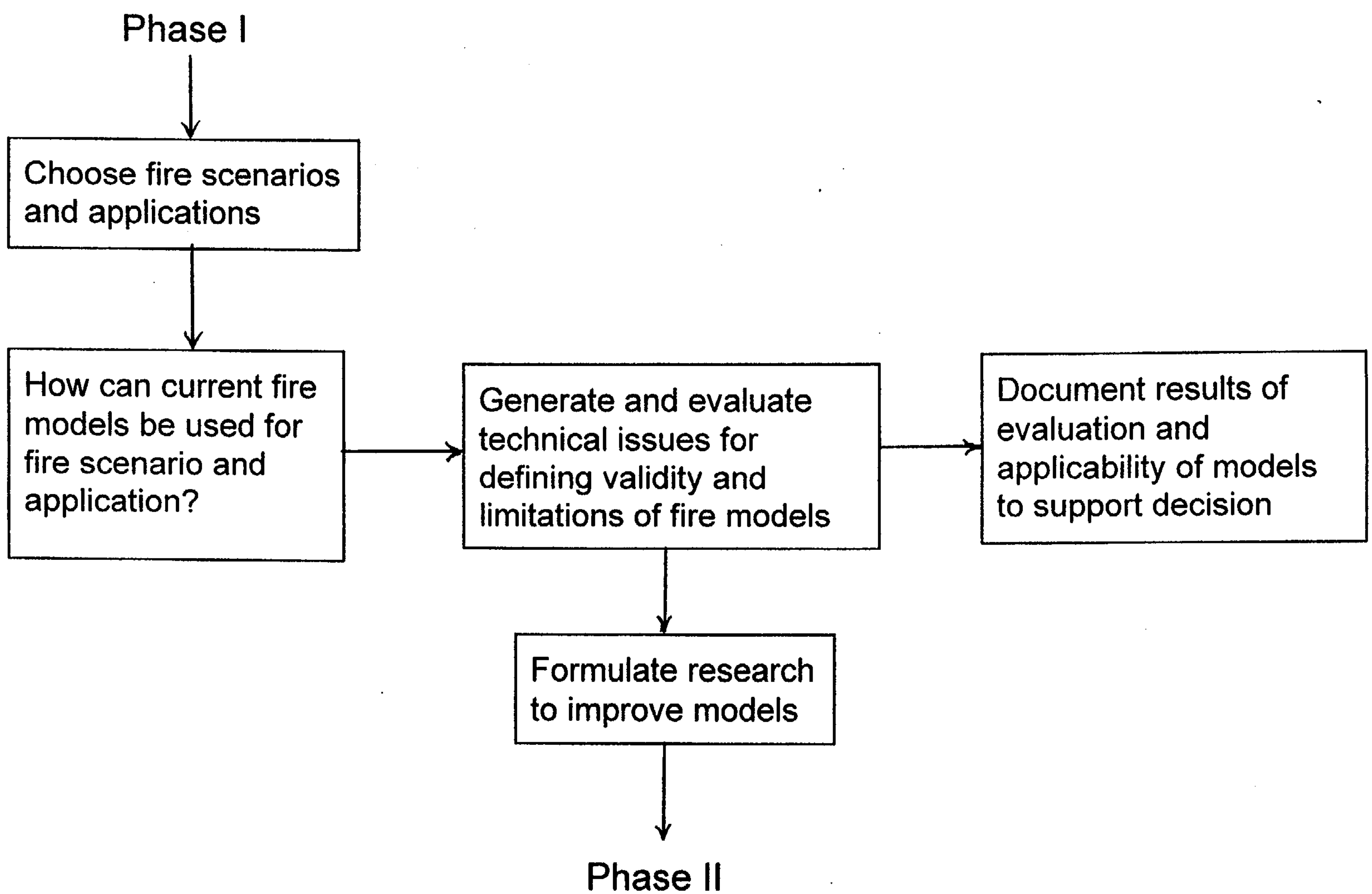
Examination of Risk from Fire Scenarios

Core damage frequency (CDF) from a fire scenario = ignition frequency of fire source x probability fire will not be suppressed before critical fire-induced damage x probability of core damage if equipment is damaged by fire

Proposed NRC Objectives

- Phase 1: Evaluate how current fire models can be used to support risk-informed decision making per NRC Regulatory Guide 1.174 on Risk-Informed Basis for Plant Changes
- Phase 2: Improve fire models to support decision making, once limitations of current models are understood and defined (this phase could include fire tests to further validate computer models)

Process to Evaluate Fire Models for Regulatory Decision Making



Proposed Applications/Fire Scenarios

- Examine two scenarios to support plant change analysis (estimate *relative risk*)
- Safe separation distance: Examine validity of fire models to support plant changes to safe separation distance of redundant cable trays (transient liquid fire source) based on calculations of time to damage and delta CDF
- Thermal barriers: Examine validity of fire models to support derating of thermal barriers in a electrical cabinet fire scenario based on calculation of delta CDF

Proposed Near-Term Milestones of Collaborative Effort

- Generate technical issues for defining validity and limitations of models to analyze *standard problems*
- Conduct independent case studies with CFAST, LES, COMPBRN, MAGIC, and FLAMME-S codes to examine code capabilities and evaluate validity of codes to support decisions
- NRC commits resources to conduct analyses with CFAST and LES codes (per NRC/NIST MOU being developed)

Other Tasks of Interest to NRC

- Investigate uncertainties and limitations of fire models for broad spectrum of fire scenarios analyzed *generally* in fire PRAs (currently planned for completion by September 2000)
- Apply analytical tools to examine risk significance of smoke effects in turbine-generator and other fire scenarios (with zone and CFD models)

Benefits of Collaborative Project

- Allows continual exchange of technical information between international organizations engaged in similar research tasks
- Decreased costs of research. Each organization can potentially engage in significant research activities without need for large investments
- Provides international endorsement and credibility to research conclusions that can support decisions in an emerging regulatory framework

Evaluation of Fire Models for Nuclear Power Plant Applications

by

R. P. Kassawara (EPRI)

B. Najafi (DS&S, formerly SAIC)

October 25, 1999

Topics

- Experience - Current Use at U.S. Nuclear Power Plants
- Need - Typical Fire Scenarios in NPP Applications
- Experimental Validation
- Proposal
- Questions

Current Use at U.S. NPPs

- Individual Plant Examination for External Events
  - For the most part FIVE, COMPBRN or a combination of the two were used
  - Both were used to calculate source-to-target exposure (temperature/flux) and time-to-damage for various fire scenarios as needed
  - COMPBRN was used on occasions to calculate propagation through stack of cable trays (intervening combustibles)

Current Use at U.S. NPPs

- Other NPP Applications
  - A survey of U.S. Nuclear Industry to:
    - fire model(s) used
    - fire scenarios evaluated
    - Purpose, i.e., in support of exemption request, insurance, life safety, etc.
    - Results and other experience insights
  - Example:
    - RCP Lube Oil Collection Performance, CFAST

Need: Typical Fire Scenarios in NPP Applications

- Fire source
  - Type: Control Panels, high-energy cabinets, oil, hydrogen, transient fires including welding, cable, etc.
  - Location: On the floor, elevated, near stairwells, vented panels, wall/corner/ceiling effects, etc.
  - Intensity/Size: HRR, duration, time-dependence, etc.
  - Point source vs. real life
  - Flame height and its impact
  - Smoke effect

Need: Typical Fire Scenarios in NPP Applications

- Compartment
  - Size: from small enclosures (e.g., main control panel) to tunnels, shafts and large enclosures such as main floors of the Auxiliary Building or Turbine Deck
  - Shape: Obstructions, enclosures within enclosures
  - Ventilation
- Fire protection features
  - Environment under full or partial suppressant discharge
  - Partial barriers
- Time-line of events (fire source & prot. features)

Typical Fire Scenarios in NPP Applications

- Examples:
  - Control cabinet fires in ventilated areas
  - Electrical fires inside main control panels
  - Elevated cable fires in long hallways
  - Multiple cable fires in stacks and across separation
  - Oil fires in large enclosures

Experimental Validation

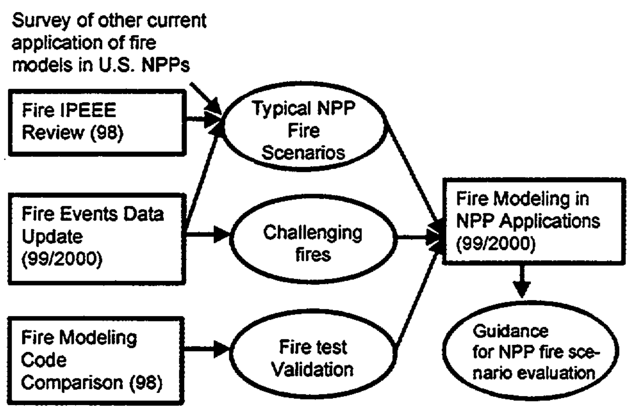
- EPRI review of FIVE, MAGIC, COMPBRN-IIIe & CFAST
  - Objectives
    - Compare their features and capabilities
    - Benchmark their results against fire tests
  - Tests
    - Single and multiple rooms, 11.6m^3 to 1362m^3 w/wo ventilation
    - Fire sources; gas burner, heptane pool, PMMA solid fires and simulated electrical cabinet fires from 500 to 2000 KW.
  - Conclusions
    - Models vary in their ability to address different fire scenarios
    - Within the constraints of the model features, models provide reasonable predictions

Related Current EPRI Activities "Fire Modeling in Nuclear Power Plants"

- Objectives
  - Evaluate selected fire modeling codes to determine their applicability to evaluation of fire scenarios in nuclear power plants
  - Provide guidance to the end user on use of the models for specific NPP fire scenarios
  - Define experimental validation tests, where necessary, that best supplement the need, i.e., typical NPP fire scenarios

Related Current EPRI Activities "Fire Modeling in Nuclear Power Plants"

– Approach



Related Current EPRI Activities "Fire Modeling in Nuclear Power Plants"

- Phase I
  - Library of typical NPP fire scenarios and key parameters
  - Plan for the benchmarking of the 4 fire modeling codes against challenging fires.
- Phase II
  - Benchmarking of the 4 fire modeling codes against actual fire events and typical NPP fire scenarios
  - Develop a guide for use of the 4 fire modeling codes for use in NPP applications
  - Define any need not met by these four codes

Proposal

- Defining the need - end users
- Validation against events - code developers or maintainers
- Proposals for further development, as necessary, to satisfy the need

October 25, 1999 Slide 12 **EPRI/NPG**

Technical Questions/Issues (to start)

- Where to start, how many codes do we evaluate? EPRI chose those most often used in U.S. NPP fire protection plus MAGIC.
- Conservatism - When is it OK to use models with less sophistication but adequate for the job at hand.

October 25, 1999 Slide 13 **EPRI/NPG**

EXPERIENCE AND NEEDS RELATED TO THE USE OF FIRE MODELS

R. BERTRAND

① **IPSN FIRE COMPUTER CODES**
② **FIRE MODELS APPLICATIONS**
③ **NEEDS FOR FIRE MODELING**
④ **PROPOSAL**

IPSN FIRE COMPUTER CODE

FLAMME-S (zone model)

- Operational fire model for fire in a room and for study of fire propagation from affected compartments to adjacent compartments
- Coupled with computer code SIMEVENT simulating the ventilation network
- Qualified with 17 IPSN fire tests without propagation(oil and solvent, mechanical or natural ventilation) and COOPER and PEACOCK propagation fire tests

ISIS (CFD-field model)

- Under development
- Study of local phenomena; for providing correlation for FLAMME-S

FIRE MODELS APPLICATIONS

FLAMME-S USE IN NPP

- **Blayais 1 (900 MWe PWR)**

  <u>FIRE PSA:</u>
  - Study of fire growth in the critical compartments
  - Study of fire propagation under progress

  <u>SAFETY ASSESSMENT:</u>
  - Estimation of pressure induced by fire (use of FLAMME-S coupled with SIMEVENT)

FLAMME-S USE IN FACILITIES

- **LECI (Laboratory test on irradiated fuel)**
- **Compartment of ATALANTE (necessity to protect metallic structure)**
- **LA HAGUE fuel reprocessing facility (to define the operating procedure to implement during a fire)**

NEEDS FOR FIRE MODELING

- **Necessity to increase the FLAMME_S qualification field:**
  - Fire area LT 7% of room ground
  - Oil DTE MEDIUM (0.03 to 5 m^2) and TBP-TPH (liquid-liquid extraction/ 1 to 5 m^2)
  - volume of compartment from 5 to 2000 m^3
  - ventilation flowrate from 3 to 5 volume/hour

  Improvement needed for:
  - large fire GT 7% of room ground
  - plume model (Gupta and Heskestad elaborated for free plume / confinement effect not taken into account)
  - thermal stratification not considered

  Qualification not carried out for:
  - solid fire notably electrical cabinet and benchboard
  - fire with plume or flamme in interaction with wall

NEEDS FOR FIRE MODELING

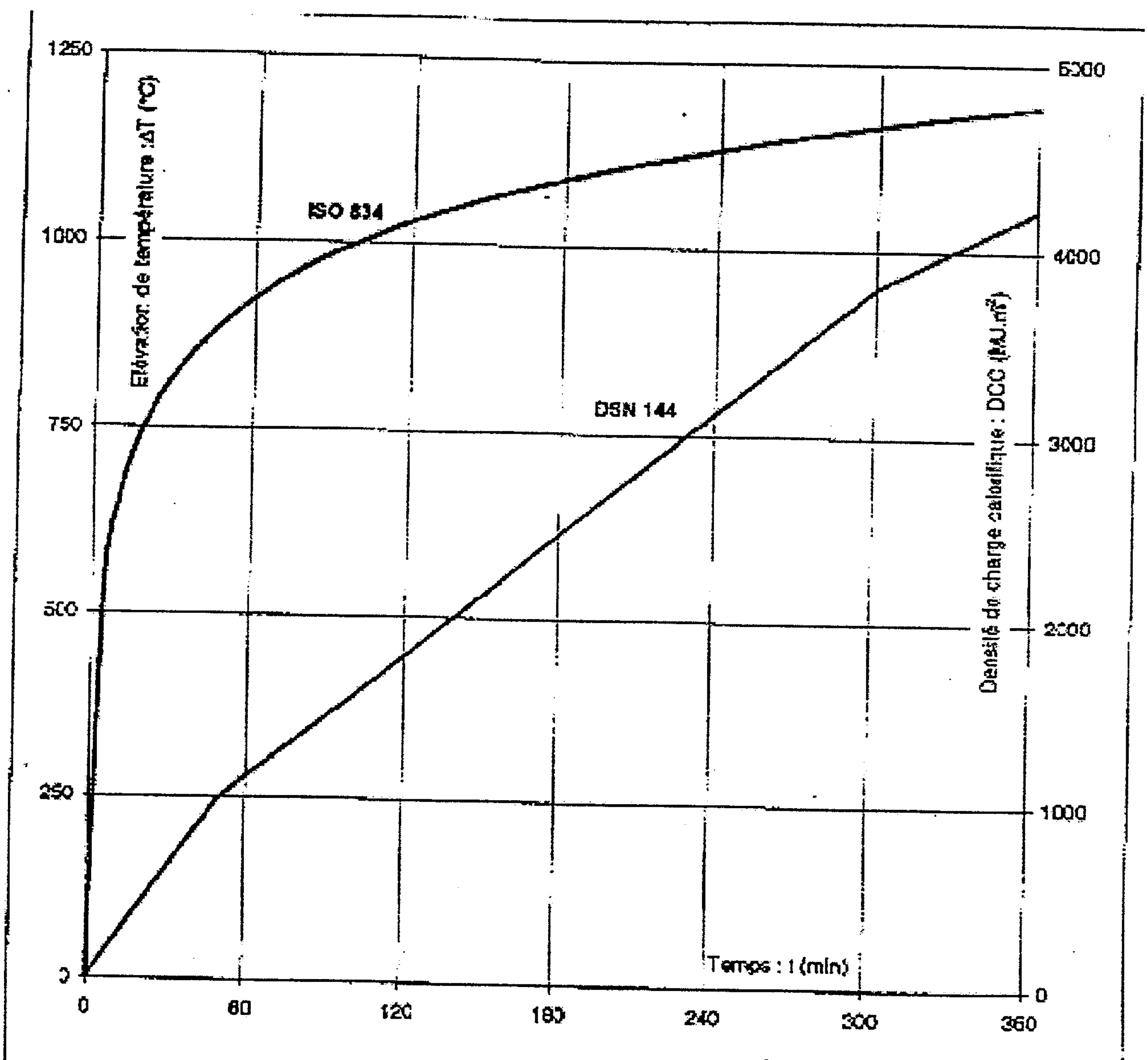


Figure 2 : Courbes (Température - temps) ou "ISO 834" et (DCC - temps) ou "DSN 144" préconisées par les RFS I.4.a, V.2.J et RR2 [1, 2, 3]

NEEDS FOR FIRE MODELING

- **Fire resistance rating of fire barriers at least equal to the duration estimated by temperature curve but this curve does not take into account parameters like:**
  - fire load distribution,
  - geometric boundary conditions (room size,height, size of openings,
  - types of combustible materials,
  - heat release rate,
  - ventilation condition.

Moreover fire tests show that this curve:

- can be optimistic for liquid combustible and for local phenomena,
- is not adapted to study the concrete resistance (hight temperature during a short time, can lead only to partial crack instead that less hight temperature during a longer time can induce through-wall crack).

⇒New Basic Safety Rule1-4a proposed by IPSN for Fire Protection in the Fuel Reprocessing Facilities

NEEDS FOR FIRE MODELING

New Basic Safety Rule (RFS 1-4a) :

- Design stage : Fire barrier rating imposed independently of temperature curve. It has to be consistent with fire suppression,
- For safety demonstration a verification is needed to show that the fire protection is sufficient. This verification should be performed using qualified fire computer code. For this it is needed to constitute a guide :
  - to define the data acceptable for each kind of fire and notably for cable and electrical cabinet fires (heat release rate, radiation coefficients , fire area, fire elevation...),
  - the assumptions acceptable (fire scenarios of interest, ventilation configuration, how to take into account the fact that large number of equipment can fill large volume of a room, thermal loss, assumptions about cable fire growth, conditions of flashover..).

Difficulty to simulate fire in large compartment (fire in the containment)

NEEDS FOR FIRE MODELING SUMMARY

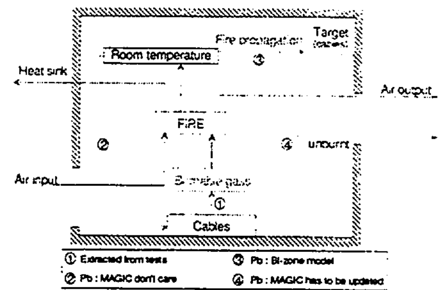
- **Improvement of fire modeling**
  - extension of fire computer code qualification,
  - improvement of fire plume model,
  - simulation of fire in a large compartment (e.g. containment)

- **Guidance for use of fire simulation**
  - Input parameters (uncertainties)
  - Appropiate approach and assumptions for fire simulation notably for electrical cabinets or cable fire

Computer fire modeling in French NPP

-
-
- Maurice Kaercher
-
- Electricité de France Septen
- 12 Avenue Dutriévoz 69628 VILLEURBANNE Cedex
-
- Phone (33) 4 72 82 73 60
- Email: Maurice.Kaercher@edf.fr

MAGIC fire modeling



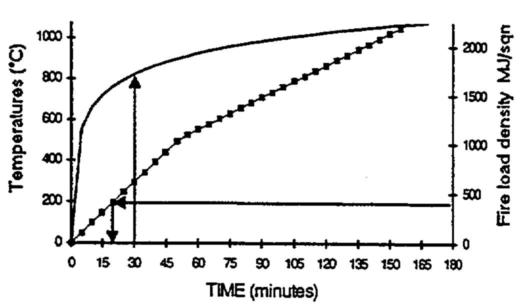
Use of computer codes and recent application in France

- Sensivity-studies
- Justification of prescriptive rules: Fire duration curve
- Fire compartment with sereval levels
- Assessment of separation by distance
- Justification of deviations (door open)

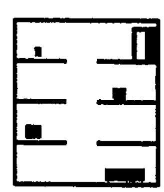
Sensivity-studies

- HRR
- Ventilation
- Insolation of the walls
- Height of the room
- Lay-out

Reference fire duration



Fire compartment with sereval levels



- Ground surface: 25 m2
- Height: 2,5 m
- Fire power: 650 kW
- Ceiling opening ration: 5 to 75 %

Main difficulty: Choice of input parameters

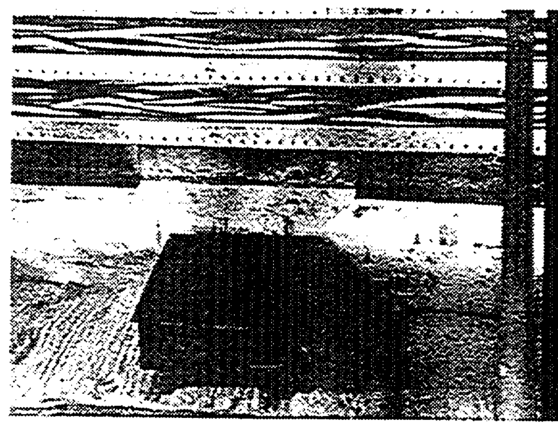
- Conservative but realistic
- Power of the fire
  - Ignition
  - Initial HRR
  - HRR versus time
  - Flash over HRR
  - Propagation
- Ventilation rate
- Leakage and faulted fire barriers

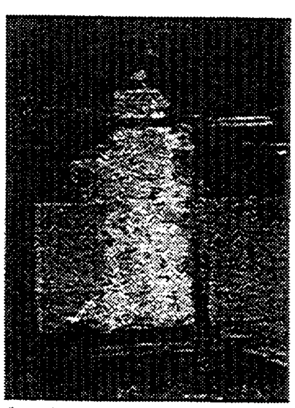
Power of the fire

- Cable specification
- Ignition: soft (heater) or strong (solvent)
- HRR (initial)
  - Best estimate tests
  - In-door tests (highest HRR)
  - Out-door tests (highest HRR)
- Flash over HRR
- Propagation

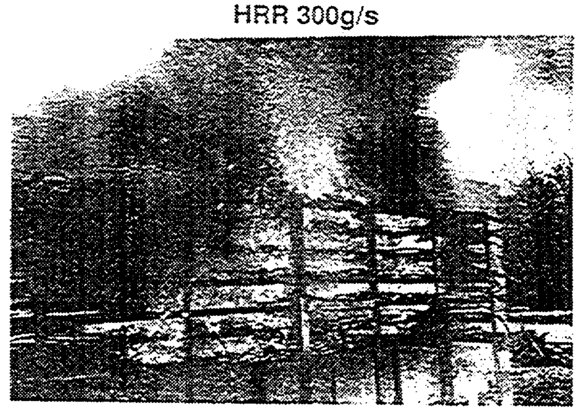
Cable specifications

- Fire retardant cables
  - French standard NF C 32-070, test number 2 (C1 criterion)
  - IEC 332-3 category B
- Halogen free cables





HRR 300g/s



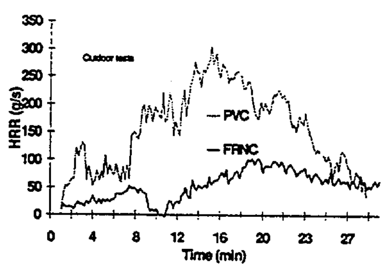
HRR Tests (1)

Test ref	Ignition			
	Nature	Power (kW)	Quantity	Time (min)
F1B	Propane	37.6		20
F2A	Propane	37.6		73
CNPP 1997	Heptane	250	18/12 L	5
LMCA 1999	Heptane	250	15/7 L	5

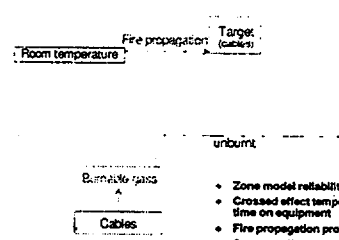
HRR Tests (2)

Test ref	Number of	Max HRR		Walls
	trays	g/s	at (min)	
F1B	3	58,9	50	Concrete
F2A	5	185,9	97	Concrete
CNPP 1997	7	111,9	31	Roof isolated
LMCA 1999	7	300/100	15/19	Outdoor

Outdoor test HRR



Main development needed



- Zone model reliability
- Crossed effect temperature-time on equipment
- Fire propagation pronostic
- Crossed effect temperature-HRR

Further needs

- Tools: no need
- Methodology: urgent needs
- Validation of input data and scenarios
  - HRR
  - Ventilation
  - Failure of equipment
  - Reliability of fire protection systems
- Guide for users
  - Assessment of installations
  - Deterministic or probabilistic
  - Design of installations (responsabilities)

SUMMARY OF FIRE CODE EXPERIENCE IN GERMANY NEEDS PROPOSALFOR PROJECT IN FUTURE COLLABORATION

M. Roewekamp
(GRS)

Planning Meeting for International
Fire Model Project
University of Maryland
College Park, MD (USA)
October 25-26, 1999

GRS

CONTENTS

- **Experience with Fire Modeling in Germany**

- **Future Needs**

- **Proposal for Collaboration**

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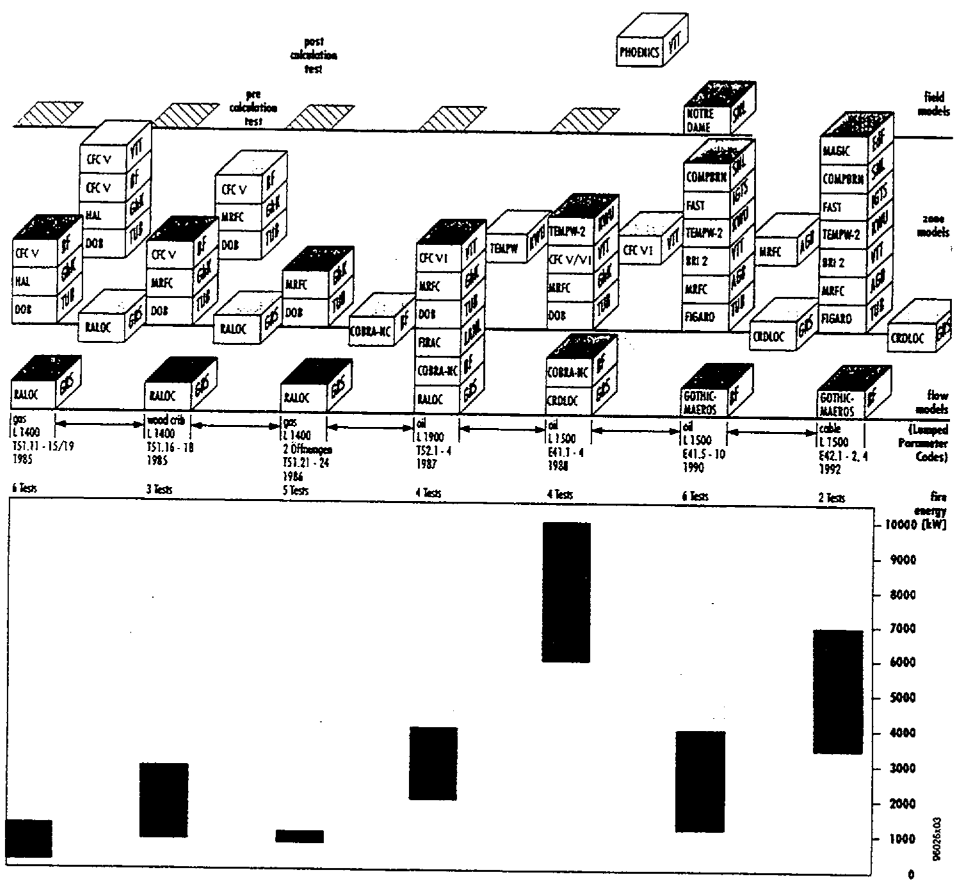
Fire Codes Participating in HDR-Program



GRS

Summary of Experiences With NPP Fire Modeling in Germany (1)

- **Meanwhile nearly 20 years of modeling experience**

- **Starting with simple zone models ➪ today more recent, partly very sophisticated multi-compartment multi-zone or fluid dynamics code systems**

- **Validation/Verification of most of the models applied**
  - by HDR experimental series (decommissioned German Heiss Dampf Reaktor)
  - by recent cable fire experiments at iBMB of TU Braunschweig
  - by different bench marks

Summary of Experiences (2)
Models applied to NPP fire simulations (1)

- **Simple zone models for calculating fire source terms of fully developed fires**
  - COMPBRN
  - DOB (by TU Braunschweig)

- **Multi-zone models for more recent risk analysis, HDR experiments calculations**
  - CFC V
  - CFAST / HAZARD
  - MRFC
  - TEMPW-2 (by Siemens)

Summary of Experiences (3)
Models applied to NPP fire simulations (2)

- **More advanced multi-compartment multi-zone codes, applied to HDR experiments and benchmark, PWR risk studies**
  - FIGARO (by iBMB TU Braunschweig)
  - MRFC (by TU Vienna)

- **3-dimensional lumped parameter codes for HDR experiments and benchmark applied to BWR risk study**
  - RALOC / CRDLOC (by GRS)
  - FIRAC (by Los Alamos Laboratories)
  - COBRA-NC (by Battelle)

Summary of Experiences (4)
Models applied to NPP fire simulations (3)

- **Highly sophisticated 3-dimensional fluid dynamics / lumped parameter codes for applications in fire hazard analyses (FPRA) and recent FPRA for PWR**
  - COCOSYS (by GRS)

- **3-dimensional field models applied to fire risk studies, mainly for nuclear installations besides NPP**
  - PHOENICS / SOFIE

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Summary of Experiences (5) Scenarios for fire simulation code applications in German NPP

- **Oil fires**
  - Turbine oil fires
  - MCP lubrication oil fires
- **Cable fires**
  - Cable fires in cable spreading rooms
  - Fire at cable distribution (starting in electric cabinet)
  - Fire in a cable tunnel
- **Combined fires**
  - Hydrogen and oil fires in turbine hall
  - MCP lubrication oil and cable fires
- **Fires in the switchgear area**

Summary of Experiences (6)
Type of fire simulation code applications in German NPP

- **Fire development and fire effects without considering active fire protection features**
- **Reliability of active fire protection features**
- **Fire resistance rating of fire barriers**
- **Analysis of efficiency and effectiveness of fire protection features on fire input on safety systems**
- **Fault tree diagrams for FPRA**

Summary of Experiences (7)
Development in Modeling

- **Advanced, partly highly sophisticated fire simulation codes available**
  - All codes worldwide are able to model fire effects in the fire near field ⇨ practically applicable
  - Multi-compartment multi-zone / node codes have been further developed
  - Modeling of fire effects in the fire far field has been improved

Summary of Experiences (8)
Applicability of fire simulation codes

- Code application for estimating / calculating necessary fire resistance rating of fire barries (uncertainties of modeling not relevant)

- Various codes applicable as basic analytical tool for FHA and/or FPRA

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Summary of Experiences (9)
Limitation of the model applications

- **Results depending on available data and modeling input ⇨**
  - Not always realistic, but too conservative as well as too non-conservative results possible
  - Controverse discussions between experts, mainly researchers

- **Tendency of using fire simulation calculation results for accident analyses in the frame of licensing and supervisory activities is still too early for a standardized approach(not state of science and technology) ⇨**
  Nevertheless, fire simulation calculation results can be helpful in particular cases

Future Needs

- **Further development of fire simulation models as validation tools to be applied in licensing and supervisory activities for NPP**

- **Minimization of uncertainties in modeling, mainly on:**
  - Ignition point / flame point
  - Burning rate and behavior
  - Pilot fire phase

- **Use of more realistic supervisory process**
  - Probabilistic assessment
  - More meaningful results on the effects of different parameters (e.g. ventilation)

GRS

Proposal for International Collaborative Fire Modeling Project

- **Exchange of results of recent projects between the participating organizations**
  - Simulation for FHA
  - Fire PSA

- **Harmonization of future projects**
  - Modeling
  - Comparison with experiments (e.g. cable fire)
  - Research activities (e.g. burning rate, fire dynamics, etc.)

- **Administrative issues**
  - Delegation of national contact persons
  - Organization of common expert meetings
  - Cross-participation in national projects
  - Check of legal basis for common activities

Summary of SMIRT 15 Post Conference Seminar No. 6 on Fire Safety in NPP and Nuclear Installations

Code Workshop

Munich, September 6-7, 1999

M. Roewekamp
(GRS)

Planning Meeting for International
Fire Model Project
University of Maryland
College Park, MD (USA)
October 25-26, 1999

Session I: Availability and applicability of fire codes for fire safety design in NPP

- Fire Simulation Tools Support Engineering Analyses for NPPs
  W. Hensel, A. Samman (Siemens KWU)

- MAGIC: The EdF Deterministic Numerical Simulation Tool for Fire Safety Assessment of NPP
  B. Gautier, O. Pages (EdF)

- Simulation of glove box fires in a nuclear fuel facility with the multi-room fire code MRFC
  C. Lebeda, U. Schneider
  (Technical University of Vienna)

- Fire computer modeling in French NPP design
  M. Kaercher, J. Gibault, M. Billaud (EdF)

Session II: Code validation and verification

- Theory versus experiment
  O. Keski-Rahkonen, S. Hostikka

- Fire propagation simulation with zone models
  D. Joyeux (CTICM)

- Numerical simulation of full scale multi-room fire tests with FLAMME_S code
  C. Casselmann (IPSN)

- An attempt of code verification using the results of full scale fire tests
  U. Max (AGB)

Session III: Scientific research on fire codes for use in NPP design

- Computer aided Heat balance calculations with FIGARO - Influence of different parameters and sub-models
  G. Blume, D. Hosser
  (Technical University of Braunschweig)

- Presentation of the GRS Analysis Simulator
  W. Pointner, W. Klein-Hessling (GRS)

- Implementation of a pyrolysis model into the containment code system COCOSYS
  W. Klein-Hessling (GRS)

- CFD-modeling of smoke detector activation in a room with a suspended perforated ceiling
  S. Isaksson (SP)

Global View

- Integration of:
  - *regulations and tools* : design framework
  - *material property standards* : material metric
  - *models and experiments* : validation and calibration
- Regulations:
  - Wolski MS: "Addressing Building Fire Safety as an Acceptable Risk-problem: A Guide for Developing Performance-based Fire Safety Regulations"

Nicholas Dembsey : ndembsey@wpi.edu
Jonathan Barnett : jbarnett@wpi.edu

NSF Support

Model Validation

- Lantz : PhD Candidate
  - *Information Theory* quantifies model structure uncertainty (*model vs. physical law*)
  - quantify predictive behavior uncertainty (*model vs. experiment*)
  - quantify information description of the data
    - information conversely related to uncertainty
  - validity of a model : sum of the 3 uncertainties
    - less uncertainty : more valid model

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Jonathan Barnett : jbarnett@wpi.edu

Maritech / Industry Support

Material Metric

- Develop experimental procedures
- Simple ignition models
  - Jacoby MS : *Fire and Materials* : "Evaluation of Common Ignition Models for Use with Marine Cored Composites"
- Composite systems
  - ignition and pyrolysis models
  - MS student

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Jonathan Barnett : jbarnett@wpi.edu

Maritech / USCG Support

Zone Models

- CFAST/Mitler and CFAST/Quintiere
  - two MS students
- Enhancement
- Calibration : experimental data
  - room tests
  - compartment IR imaging
    - Choi : PhD Candidate

Nicholas Dembsey : ndembsey@wpi.edu
Jonathan Barnett : jbarnett@wpi.edu

Field Models

- Pehrson PhD: "Prediction of Fire Growth on Furniture Using CFD"
- Ierardi : PhD Candidate, NIST Support:
  - computational fluid dynamics modeling of ionization-type smoke detectors
- Senior Project, VUT (Australia) Support:
  - prediction of post-flashover fires using CFD

Nicholas Dembsey : ndembsey@wpi.edu
Jonathan Barnett : jbarnett@wpi.edu

Chairmanships

- SFPE Room of Origin Fire Hazards TG
  - fire environment simulation
  - response of targets simulation
- CIB W014 : Fire : 99-5 Compendium of Reference Cases for Validating the Performance of Zone and Field Models

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Jonathan Barnett : jbarnett@wpi.edu

Potential Usefulness of CIB* W14 Evaluation to the Project

Matti Kokkala
Coordinator of CIB W14: Fire

VTT Building Technology
Fire Technology
P.O. Box 1803, 02044 VTT
FINLAND
http://www.vtt.fi/rte/firetech

*CIB = International Council for Research and Innovation in Building and Construction (www.cibworld.nl)

CIB W14 / Sub-Group 2 (1994 - 1999)

Assessment and Verification of Computer Fire Codes for Predicting Fire Development and Smoke Movement

- **Chair: Olavi Keski-Rahkonen, VTT (olavi.keski-rahkonen@vtt.fi)**
- **Scope and Objectives**
  - to increase confidence in the use of models as tools for fire safety engineering
  - to support ISO/TC92/SC4 in its efforts on assessment and verification of calculation models
  - to consider all aspects of code evaluation, including physics, numerics, documentation, use of the codes, and availability of appropriate data for the selected scenarios, and
  - **to carry out a round robin project on deterministic numerical fire simulation computer codes and experiments for model evaluation**

Simulation Round Robin ("blind simulation")

- Round A: 1995 - 1996
  - 21 participants from 11 countries
  - 10 zone model codes and 3 CFD codes
  - Constant HRR with step wise increase and decrease
  - Single enclosure with sudden changes in openings (no experimental results)
- Round B: 1996 - 1997
  - 16 participants from 10 countries
  - 9 zone model codes and 2 CFD codes
  - Wood crib fires in a large enclosure (blind simulation; experimental data available)

Procedure

- Round A
  - heat release rate vs. time, thermal properties of boundaries, openings vs. time given
  - four different size enclosures (scaling for convection)
- Round B
  - wood crib fuel load (type, amount, location) and enclosure properties (geometry, openings, thermal properties) described
  - burning rates in experiments given as files
  - second round with experimental results available.

Conclusion / Round A

- **"Most of the variables can be predicted at least by a factor two (many of them much better)"**
- Reference: Olavi Keski-Rahkonen, CIB W14 Round Robin on Fire Simulation Code Comparisons, Fire and Explosion Hazard of Substances and Venting of Deflagarations, Proc. of the 2nd International Seminar, 11-15 August 1997, Moscow, Russia, Ed. V. Molkov, All-Russian Research Inst. for Fire Protection, 1998, pp. 87 - 101.

Conclusions / Round B

- **Everyone could reproduce, even blindly, the main features of the experiments;**
- **Quantitatively, there were deviations ranging typically from +/-20% up to a factor 2 (or 5?);**
- **All of the results had features that indicated a discrepancy with the experimental data in the blind simulations, but which could be improved during the open round by choosing alternate submodels and/ore changing optional parameters;**
- **Where several persons used the code, the dependence of the results on the user was demonstrated**
- Ref.. Simo Hostikka & Olavi Keski-Rahkonen (with editorial help of J. Barnett), results of CIB W14 Round Robin for Code Assessment: Scenario B (unpublished draft - conclusions not agreed by participants), 1998.

Lessons learned

What was good:

- a learning process to all participants
- global interest
- significant problems highlighted

What has been criticised:

- over ambitious: "a fifteen-year project" (considering voluntary participation)
- too complicated task to start with (step-wise changes)
- code and user problems mixed
- fire source outside of the validity of plume models

Continuation within CIB W14

Compendium of reference cases for validating the performance of zone and field models (contact: J. Barnett / WPI)

- The project aims at improving the quality of the models and their use by compiling a set of reference cases, which can be used both by the model developers and the engineers using the models. The reference cases will vary in scale and complexity to challenge the models sufficiently for different purposes.

- The schedule of the project is to provide a first draft by *1 April 2000* to be discussed at the W014 annual meeting in June. The final draft is to be submitted for review to the members by *1 February 2001* and for discussion at the subsequent Working Commission meeting. The document will be submitted for publication by *30 September 2001*.

Definitions

(Guide for Verification and Validation of Computational Fluid Dynamics Simulations, AIAA, Guide G-077-1998)

- ***Verification:*** **The process of determining that a model implementation accurately represents the developer's conceptual description of the model and the solution to the model.**
- ***Validation:*** **The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.**

Definitions

(AIAA Guide G-077-1998)

- *Model:* **A representation of a physical system or process intended to enhance our ability to understand, predict, or control its behaviour.**
- *Modeling:* **The process of construction or modification of a model.**
- *Simulation:* **The exercise of use of a model. (That is, a model is used in a simulation).**
- *Prediction:* **Use of a model to foretell the state of a system under conditions for which the model has <u>not</u> been validated.**
- *Uncertainty:* **A potential deficiency in any phase or activity of the modeling process that is due to lack of knowledge.**
- *Error:* **A recognizable deficiency in any phase or activity of modeling and simulation that is not due to lack of knowledge.**

Fire Modelling in the Built Environment

Prof Geoff Cox
UK Fire Research Station
Chairman ISO TC 92 'Fire Safety'

Content of Presentation

- **ISO TC92 activities**
  - consequences of FSE for structure & work programme for ISO
- **UK FRS activities**
  - 20 years of CFD fire model evaluation
  - also risk model CRISP

ISO TC92

- Title changed in 1995 from **'Fire Tests on Materials, Components & Structures'** to **'Fire Safety'**
- This change reflected emergence of Fire Safety Engineering and implications for standardisation of fire safety
- Work on FSE had been underway since 1992 within TC92/SC4

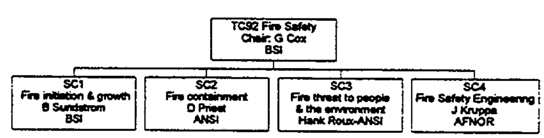
ISO TC92

- 1999 sees re-structuring of TC92 (May)
  - to encourage development of new standards for use in FSE
  - to take the initiative in coordination with other ISO/IEC committees & liaison with international 'users' of standards (eg IMO)
- publication of FSE Technical Reports (October 15)

ISO TC92

- develop proposals for a framework for long term future for fire safety standardisation

ISO TC92 structure



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FSE documents

- The SC4 Fire safety engineering Technical Reports 13387 Parts1-8:
  - 1. The application of fire performance concepts to design objectives
  - 2. Design fire scenarios and design fires
  - 3. Assessment & verification of mathematical fire models

FSE documents

- 4. Initiation & development of fire & generation of fire effluent
- 5. Movement of fire effluent
- 6. Structural response & fire spread beyond the enclosure of origin
- 7. Detection, activation & suppression
- 8. Life safety: occupant behaviour, location & condition

Probable new SC4 work-1

- standard on design fire scenarios & design fires
- standard on verification & validation of math. fire models (zone & CFD)
- technical report on experimental data needed for FSE
- technical report on enhancing quality & added value of fire test methods

Probable new SC4 work-2

- Technical report on risk assessment including safety criteria
- technical report on movement of people

Draft 'FSE' test requirement

- that 'product' performance in the test is provided in quantitative terms for known, controlled and varied exposure conditions
- that exposure conditions must be provided in quantitative form and must be representative of in-use fire exposures
- that processes in the test are sufficiently well prescribed that they can be modelled
- that performance, as described above, from the particular conditions of the test must then be translatable by predictive methods to in-use behaviour in the design environment

ISO TC92

- develop proposals for a framework for long term future for fire safety standardisation

UK Fire Research Station

Background

- FRS have been developing Reynolds averaged Navier Stokes CFD models since 1973
- continuous process of 'verification'-now offer consultancy to commercial clients for smoke movement problems based on highly developed, Cartesian, first order upwind code JASMINE

Verification

- first 'verifications' included very simple experimental compartment scaling laws
- 'verification' studies have included the 1982 LLNL experiments and many other-all in public domain
- JASMINE code is 'mature' and in the 'right hands' reliable!

SOFIE code-1

- New code under simultaneous development by consortium of national fire labs (FRS, VTT, SP, CSTB, U of Lund, UK Home Office, UK HSE, Cranfield U)
- objective is that SOFIE be an 'open source benchmark' see http://www.cranfield.ac.uk/sme/sofie/
- code has more 'modern' numerics

SOFIE code-2

- developments include flame spread, vitiated kinetics etc
- code is still under development and as yet less reliable

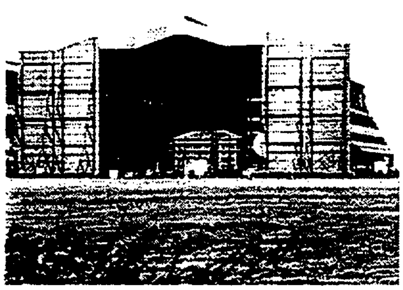
Recent model evaluation studies-1

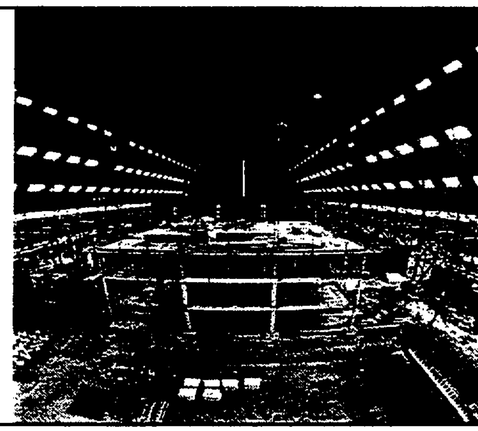
- BRE Large Building Test Facility (UK DETR report to be published October 1999)
- same facility, different 'blind' data (1998) for CIB W014?
- CIB W014 VTT facility but 'blind data'- (FRS publication on JASMINE application, IAFSS Poitiers Conference 99)

Recent model evaluation studies-2

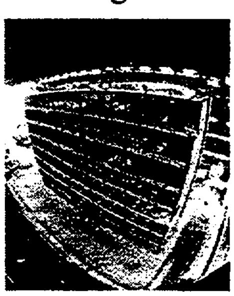
- UK Steel Construction Institute fires conducted by SINTEF (UK DETR report 1998 , SCI report 1995)
- Memorial Tunnel Fires (by Bechtel in 95 for Mass. Office of Transportation-various publications)
- sprinkler-layer interactions (one head, 1MW pool fires)

Cardington Laboratory



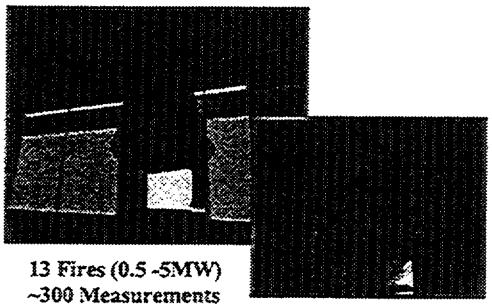


Large Building Test Facility



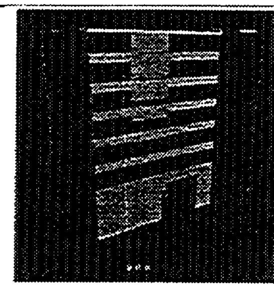
Cardington

Example



13 Fires (0.5 -5MW)
~300 Measurements

Calculation Domain

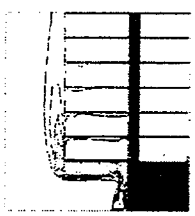


Domain extended beyond front of building

Fixed pressure boundaries on sides and top, floor is blocked.

26m wide
21m deep
33m high

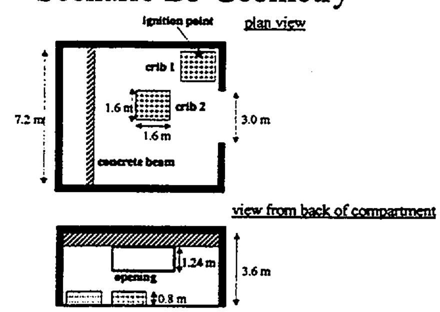
Results(1)



Temperature contours on a vertical plane through the fire.

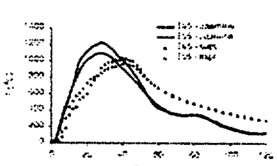
Shows fire leaning toward back wall and external plume

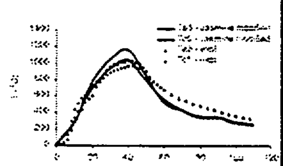
Scenario B3 Geometry



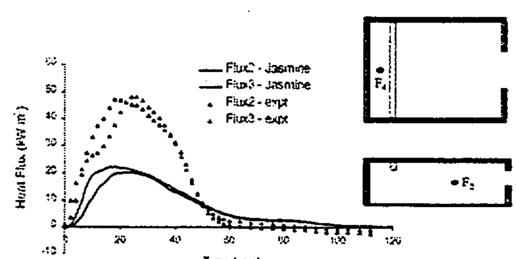
Adjusted Temperature Prediction

- Prediction 'modified' according to varying heat of combustion





Predicted & Measured Fluxes



New studies

- European Coal & Steel Community project
  - VTT, ARBED, AGB (Germany), LABEIN (Spain), 3 years from 1999
- thermal behaviour of structural elements insteel/composite frame buildings subject to 'natural' fires not standard curve

ECSC programme

- Use:
  - BRI Japan steel beam data
  - new data from VTT, heptane pools
  - BRE/FRS data, wood/plastic fuels (40 MW)

Lessons & issues-1

- Some lessons:
  - essential that expts & simulations are conducted simultaneously-can be expensive!
  - education & best practice guidance needed for model users (user a bigger problem that the model?)
  - next generation instrumentation needed for proper CFD (both RANS & LES) verification

Lessons & issues-2

- Many technical issues remain but CFD can be used with confidence, in the right hands, to tackle 'smoke movement' problems
- outstanding problems:
  - coupling 'near field' resolution to 'far field'
  - soot & thermal radiation
  - gas/solid phase heat transfer
  - flame spread
  - vitiated kinetics etc, etc

Update on Performance-Based Codes and Standards at NFPA

Doug Beller, PE
International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications
25-26 October 1999

Presentation Outline

- **Brief history**
- **Overview of Task Group Report**
- **Technical Committees Involved**
- **The Future**

Brief History

- **NFPA In-House Task Group on Performance-Based Codes and Computer Fire Models - 18FEB1994**
- **NFPA Board of Directors Ad-Hoc Task Group on Performance-Based Codes and Standards**
- ***NFPA's Future in Performance-Based Codes and Standards*: - released July, 1995.**

NFPA's Future in Performance-Based Codes and Standards - I

- **Terminology**
- **Why a standardized approach to performance-based design is needed**
- **Other groups pursuing performance-based initiatives**
- **Components of a performance-based documents**

NFPA's Future in Performance-Based Codes and Standards - II

- **New elements for NFPA's standards making system**
- **Document conversion process**
- **Process for everyday practice**
- **Work with Technical Committees**

NFPA's Future in Performance-Based Codes and Standards - III

- **White paper: "Performance-Based Codes and the NFPA"**
- **Performance-based codes bibliography**
- **Prototype performance-based document**

"New Elements..."

"It must be acknowledged that the arrangements for sanctioning model users and for *establishing acceptance of fire models* need to be defined more precisely. This activity is essential to the success of performance-based design and should receive top priority."

Technical Committees Involved - I

- **NFPA 251, Fire Tests of Building Construction and Materials**
  - **What information should be provided?**
  - **And how or in what format?**

Technical Committees Involved - II

- **NFPA 72, National Fire Alarm Code ®**
  - **Considered performance language at F96 meeting**
- **Approved May, 1999**
  - **Chapter 8 is performance-based**
- **Next step, entire document?**
  - **Factors to consider...**

Technical Committees Involved - IIIa

- **NFPA 101, Life Safety Code ®**
  - **Initially, Health Care**
  - **All Occupancy Committees**
  - **Fundamentals**

Technical Committees Involved - IIIb

- **101 Fundamentals developed:**
  - **Goals**
  - **Objectives**
  - **Criteria**
  - **Scenarios**
- **Reliability and uncertainty are issues**
  - **To be voted on F99**

Technical Committees Involved - IV

- **NFPA 914, Fire Protection in Historic Structures**
  - **Approached Support Team for assistance**
  - **Insist 'historic fabric' remains intact**
  - **Solution provided: performance to be determined**

Technical Committees Involved - V

* NFPA 76, Protection of Telecommunications Facilities
  * New committee, no prescriptive NFPA standard
  * Drafts have been prepared
    * Started with prototype from report

Technical Committees Involved - VI

* NFPA 664, Prevention of Fire and Dust Explosions in Woodworking Facilities
  * Pro-active and knowledgeable chair
  * Ambitious undertaking:
    * Expand entire document
    * Add performance-based provisions

Technical Committees Involved - VIIa

* NFPA 805, Fire Protection of Nuclear Facilities
  * Prescriptive 803 and 804 not used in US: CFR takes precedence
  * NRC provided impetus for performance-based document
  * Many drafts developed

Technical Committees Involved - VIIb

* NFPA 805 Technical Committee to defer to SFPE Computer Model Evaluation Task Group
* "Acceptable" and reliable models are needed, but...
* NFPA Technical Committees must rely on others.

Technical Committee Overview

The Future

* Currently "Occupancy" type documents
* Installation documents expected to follow

Conclusion

* Still in the early stages
* Learning as we go
* Unforeseen issues
* Performance-based provisions will be (and already are) a reality within NFPA documents

COMPUTER FIRE MODEL UNCERTAINTY: BASIS FOR A DESIGN SMOKE LOAD

Douglas Beller, PE
National Fire Protection Association, USA

ABSTRACT

This paper presents a conceptual model for design smoke load. A design smoke load in the context of this paper is intended to be analogous to the design loads specified in structural engineering: a sufficiently significant threat to safety having a sufficiently low probability of occurrence. The problem with specifying a design smoke load is that there are many factors to consider and there is a given amount of uncertainty associated with each of these factors. Therefore, it is difficult to specify a design smoke load because it is not readily known how these uncertainties may be determined and how they may interact. This paper proposes a methodology for specifying a design smoke load for office settings that accounts for uncertainties in computer fire effects models (i.e., fire models).

INTRODUCTION

One of the concepts that fire safety engineering can borrow from structural engineering is that of the limit state equation; which can be stated as, "the strength of the structure must be greater than the sum of the loads."[1] In structural engineering, loads and strength (or resistance to the loads) are expressed in units of kg-m (ft-lb). However, in fire safety a more reasonable measure to use for load and resistance is time. Since fire is a dynamic process, the emphasis in fire safety engineering is to do "something" before the fire adversely affects whatever is being protected. Essentially, fire safety systems are in a race with the fire. For example, smoke management systems must remove smoke before untenable conditions are realized. In this case, the development of smoke is the load (i.e., how long it takes for smoke to attain a given condition), and the resistance to that attaining that condition is provided by the smoke management system. The design of a smoke management system may become complex and require the use of various models, typically in the form of computer software.

While fire safety designers must rely on models, they must also address the uncertainty associated with those models, including uncertainties associated with assumptions, parameter estimates, and relevance of scenarios. For a designer, addressing uncertainty is not just a matter of quantifying the uncertainty; it involves incorporating the uncertainty into the specification of control parameters, like design smoke loads. If explicit attention to uncertainty is rare, and it is, incorporation of uncertainty into design control parameters is even more rare, but it is essential to having a practical effect. This paper will describe a technique for incorporating uncertainty into a design smoke load specification, as an illustration of a more general approach needed by the design community.

The problems associated with accounting for uncertainty are compounded in fire safety design because the designer must deal with more uncertainty than that associated with only a fire model; there are human aspects that must be considered. For example, if the level of smoke in an egress path is the problem to be solved, at what height above the floor does the designer assume that tenable conditions must be maintained? While the actual height of the smoke level may be prescribed (e.g., ranging from 1.7 - 2.0m or 5.5 - 6.5ft), keeping smoke above that level does not necessarily protect all persons who may use the building: some people will pass under the smoke, while others will have to bend over to avoid it. Essentially, there is an uncertainty associated with the heights of the people who may use the building and their willingness or ability to travel through smoke to escape.

This "human" uncertainty is compounded by the uncertainties associated with fire models, which are typically not well known. Fire models are based on experimental test results which are subject to measurement uncertainties, typically on the order of 10 to 20 percent[2], depending on the parameter of interest. The height of smoke above the floor is typically reported as a single value and may be based on different measurements; e.g., temperature or obscuration. Typically, these two techniques provide different values and the designer (and reviewing authority) are faced with the problem of too much uncertainty in the resultant design: which of these two values is, or may be, correct?

There is little that the fire safety designer can do to reduce the "human" uncertainty. It would be unreasonable for the designer to have a plaque installed in the entrance of the building excluding people who are too tall for the design. However, a design smoke load may mitigate the uncertainty problems associated with the fire model used (and may indirectly address the "human" uncertainty, also). A design smoke load is intended to be analogous to the building design loads used by structural engineers: a sufficiently high load having a sufficiently low probability of occurrence. This paper describes a methodology which uses fire model predictions and associated uncertainties as a basis for a design smoke load.

A "BETTER" MODEL OF REALITY

One problem a reviewing authority can have when presented with a fire safety design based on fire models is a lack of confidence in the predictions of the fire model: how well does the fire model actually predict reality? There are several ways to measure reality. Full scale fire tests are perceived as being an accurate measure of reality, although they are usually too expensive to run. Field data and expert experience are also viewed as measures of reality, but these may not apply to the design scenario. Another method of measuring what is more real than a model is using a "better" model. In the case of fire safety design, relatively unsophisticated zone models are used most often. Computational fluid dynamics models are more sophisticated than zone models, but are also time intensive and expensive. Therefore, fire safety designers have few choices to test the validity of their designs. This paper provides the proof-of-concept for an alternative "better" model which a reviewing authority may use as a "reality check" on a proposed design.

This "better" model will consist of combining the knowledge represented in two models that describe the development of smoke resulting from a prescribed fire. These models, FPEtool[3] and CFAST[4], are assumed to contain the current state-of-knowledge regarding the behaviour of smoke generated by fires in buildings. The author recognizes that there are additional models (e.g., WPI/Fire[5] and CONTAM[6]) that can also be used to construct a "better" model. However, it is believed that FPEtool and CFAST will suffice to demonstrate proof-of concept such that these additional models, and others, may be incorporated in the future.

THE PROCESS

Developing a "better" model is a multi-step process, as discussed below.

Defining the Metric of Interest

The first step in developing a design smoke load is to decide what the measure or characteristic of interest should be. As indicated above, there is some question concerning the height above the floor at which the smoke level should be maintained. There are two aspects to specifying this height: 1) the range of heights of people that may occupy the building, and 2) the uncertainty associated with measuring, reporting and predicting the height above the floor of the interface between the smoke and the uncontaminated air below it. (Part of the problem associated with the second aspect is that the demarcation between the smoke and the uncontaminated air below it is not well defined and can be a subjective measure.)

The metric chosen to define the design smoke load will be the time required to fill the volume of the room of fire origin above 2.13m (7ft) with smoke, t_{int}, or "time of interest." This metric was chosen because it is assumed to be conservative since the intent is to maintain the smoke level at least 2.13m above the floor of the room of fire origin. This should account for both the range of heights and the variance in the "actual" level of the interface. Furthermore, the height of a typical office door in the United States is 2.13m. When the smoke level descends below the top of the door, a "phase change" occurs in the dynamics of the fire; the flow characteristics through the door change (assuming it is open) and this affects the fire. The intent of the design smoke load is to maintain the smoke level above the height where this phase change will occur so that most people will not be affected.

The Conceptual "Better" Model

With the metric chosen the task becomes one of how to build a "better" model. How can two (or more) fire models be "combined" to provide "better" predictions than the individual models alone? The answer proposed by the current work is to develop a response surface that represents the combining of predictions of two (or more) fire models and then to apply an uncertainty distribution to the results of the response surface. This "better" model formulation is based on the assumption that the fire models used in developing the "better" model represent all that is currently known about the development of smoke from fires. Therefore, if the predictions of individual models can somehow be combined, the result would provide the desired "better" model. The technique chosen to combine the individual fire models is response surface analysis.

The response surface will be developed based on generic fires, specifically those that vary with the square of time. The uncertainty distribution will be based on comparing the predicted output of the individual models to data obtained from full-scale tests and experiments.

RESPONSE SURFACE DEVELOPMENT

A response surface "...seeks to relate a response or output variable to the levels of predictors, or input variables, that affect it."[7] In this case, the output variable is t_{int}. The input variables are the subject of the analysis. First, a choice must be made regarding which input variables may be appropriate, and secondly, choices must be made about which combinations of those input variables should be used.

The fire model input variables have been chosen from two ad hoc categories: passive geometric and active geometric. A passive geometric variable is defined as one that is geometric in nature and does not directly affect the physics. The smoke filling volume (i.e., that which is to be filled by t_{int}) is the passive geometric variable of choice. An active geometric variable is defined as one that is geometric in nature and does directly affect the physics. The height of the base of the fire above the floor is the active geometric variable of choice. This variable effectively defines the plume entrainment height and thus in part determines t_{int}. The choice of these two input variables is preliminary and not meant to be definitive.

Further work will be done to identify which input variables should be used to provide a more fundamentally based "better" model. These input variables are sufficient for the proof-of-concept nature of the current work. (Indeed, the above formulation does not account for any fire physics. For this proof-of-concept effort only "slow t-squared" fires were used. Medium, fast, and ultra-fast t-squared fires will be used at a later date.)

Since the current work is intended to show proof-of-concept, a simple linear formulation was selected. Once again, this is not meant to be a definitive choice. Therefore, the response surface is assumed to be of the form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \qquad [1]$$

where y is the output variable (i.e., t_{int} as predicted by FPEtool and CFAST)
x_i are the input variables (i.e., smoke filling volume (SFV), height of base of fire (HBF))
β_i are the coefficients to be determined.

From Reference 7, the process to determine the β's is to first select representative levels of the input variables SFV and HBF: three of each were chosen. This results in nine different slow t-squared fire cases for both FPEtool and CFAST (i.e., 18 in all). Two matrices are constructed next, one containing the predicted values of t_{int} (denoted by y) and the other containing the input variables (denoted by z) as shown in Equation 2 below. Converting Equation 1 into matrix format results in :

$$z'z\,\theta = z'y \qquad [2]$$

where θ is the matrix containing the β's of Equation 1
z' is the transpose of z.

The solution of Equation 2 is:

$$\theta = (z'z)^{-1}\,(z'y) \qquad [3]$$

where $(z'z)^{-1}$ is the inverse of the matrix z'z.

The solution of Equation 3 is a least squares estimation[7]:

$$\theta = \begin{bmatrix} 1.8211905 \\ 0.2204792 \\ 0 \end{bmatrix}$$

Therefore, the response surface that approximates t_{int} as predicted by both FPEtool and CFAST is:

$$t'_{int} = 1.821 + 0.220\,(\mathrm{SFV}) \qquad [4]$$

Note that since $\beta_2 = 0.0$, the expression for t'_{int} is linear in SFV only.

In order to avoid numerical problems during the matrix calculations, the input values were coded (see Table 1, below). The coding for HBF is a simple linear transformation: a factor of 3.279. The coding for SFV is also linear:

$$SFV_i = (x - SFV_{avg}) / (113.6 - SFV_{avg}) \quad [5]$$

where SFV_i are the coded values of SFV used in the z matrix of Equation 2
SFV_{avg} is the average value of the three SFV's used.

Table 1 presents the input values used and their coded values, and the values of t_{int} as predicted by the individual fire models and the response surface of Equation 4. The values of t_{int} predicted by FPEtool and CFAST were also coded (using $\log_{10}$) before performing the matrix calculations, but these coded values are not shown in Table 1.

Table 1 indicates that this preliminary "better" model of smoke filling in the room of fire origin is qualitatively good. The fitting procedure used is the method of least squares and "selects, as the best estimate of θ, the value that makes the sum of squares of [the residual values, $\varepsilon = t_{int} - t'_{int}$] as small as possible."[7] The residuals that are shown in bold are those values which exceed the 20% experimental uncertainty. Thus, additional work is needed to reduce these residuals (possibly assuming a nonlinear model), but the process for developing a "better" model has proved to be viable.

1. Response Surface Variables

SFV		**HBF**		**Eq. 4**	**FPEtool**		**CFAST**	
m^3	**Coded**	**m**	**Coded**	**t'_{int} (s)**	**t_{int} (s)**	**ε**	**t_{int} (s)**	**ε**
2.72	-3.03	0.0	0	14.2	15.2	1.0	10.7	**-3.5**
2.72	-3.03	0.305	1	17.1	18.0	0.9	11.0	**-6.1**
2.72	-3.03	0.915	3	24.6	26.7	2.1	14.5	**-10.1**
113.3	1.0	0.0	0	110.1	123.5	13.4	127.0	16.9
113.3	1.0	0.305	1	132.2	137.5	5.2	140.3	8.1
113.3	1.0	0.915	3	190.6	174.9	-15.7	173.3	17.3
141.6	2.03	0.0	0	185.7	170.0	-15.7	240.0	**54.3**
141.6	2.03	0.305	1	223.0	191.1	-31.9	262.1	39.1
141.6	2.03	0.915	3	321.6	246.5	**-75.1**	310.0	-11.6

UNCERTAINTY DISTRIBUTION

The response surface described above is not based on "real world" fires. The time-squared fire can be likened to those used in furnace tests: well behaved, not necessarily a realistic representation of a fire that may be experienced in the field. Incorporation of this "real world" aspect into the design smoke load will be accomplished with the application of an uncertainty distribution. The basis for this uncertainty distribution is taken from two previous studies[8,9], plus some more recent work. In these studies, computer fire model predictions are compared to data from tests involving various types of fires, including burners and those involving "real" fuels. The metric of uncertainty, UNC, is the ratio of the predicted value of interest (in this case, t_{int}), over the experimental value. Thus, if UNC is greater than 1, the model overpredicts the experimental value, while a value less than 1 is an underprediction.

The uncertainty histogram shown in Figure 1 is based on the FPEtool and CFAST predictions of t_{int} and should be considered preliminary since it is based on a limited number of comparisons. Additional comparisons are expected to be performed in the future and those will be used to update this histogram.

Figure 1. FPEtool/CFAST Uncertainty Histogram

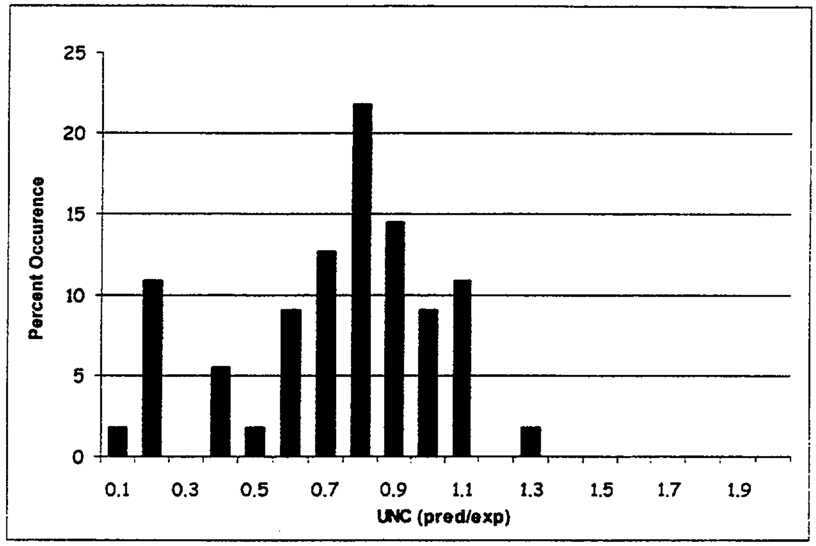


Figure 1 indicates that the "better" model (i.e., the combination of FPEtool and CFAST) tends to underpredict the time of smoke filling to 2.13m above the floor by a factor of approximately 0.8.

DESIGN SMOKE LOAD

The design smoke load can be used by a designer as a preliminary screening tool to assist in developing the smoke related input data for various fire models. The designer can specify the geometry under consideration, and the performance criteria, and the design smoke load will then provide the range of input values to be used with a fire model. In this way the designer ensures that the smoke related values predicted by the fire model are within the experimental uncertainty measured during testing. Presumably, if a fire model can predict the value of the parameter of interest to within the same uncertainty associated with the test measurement, then the fire model should be an acceptable tool to use for fire safety design.

Alternatively, the design smoke load may be used by an authority during the review of, for example, a smoke management system. The authority would first use the response surface model to determine an approximate time for smoke to fill the volume of the room of fire origin greater than 2.13m above the floor. The uncertainty distribution can then be used to determine a range of values and the most likely value within that range.

CONCLUSION

This paper has demonstrated the proof-of-concept for a "better" model of smoke development from fires that may be used as a design smoke load. The work discussed is at a preliminary stage and therefore can not as yet be used for practical purposes. Additional input variables must be tested and other combinations of them used to develop a response surface with a lower level of error. Also, more comparisons of model predictions and experimental results must be undertaken to ensure a statistically valid uncertainty distribution.

REFERENCES

1) Lucht, D.A., "Public Policy and Performance-Based Engineering," Proceedings 1996 International Conference on Performance-Based Codes and Fire Safety Design Methods, ed. D.P. Lund, Society of Fire Protection Engineers, Boston, MA. 1997.

2) Madrzykowski, D., National Institutes of Standards and Technology, Building and Fire Research Laboratory, personal communication.

3) Nelson, H.E., FPEtool: Fire Protection Engineering Tools for Hazard Estimation, NISTIR 4380, National Institute of Standards and Technology, Center for Fire Research, Gaithersburg, MD, 1990.

4) Peacock, R.D., Forney, G.P., Portier, R., and Jones, W.W., CFAST, the Consolidated Model of Fire Growth and Smoke Transport, NIST Technical Note 1299, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, MD, 1993.

5) Satterfield, D.B and Barnett, J.R., User's Guide for WPI/Fire Version 2 Compartment Fire Model, Worcester Polytechnic Institute, Worcester, MA, 1990.

6) Walton, G.N., CONTAM96 User Manual, NISTIR 6056, National Institute of Standards and Technology, Gaithersburg, MD, September, 1997.

7) Box, G.E.P. and Draper, N.R., Empirical Model-Building and Response Surfaces, John Wiley & Sons, New York, 1987.

8) Beller, D.K., "Computer Fire Model Validation: FPETOOL, CFAST, WPI/FIRE," International Conference on Fire Research and Engineering, Orlando, FL, 1995.

9) Beller, D.K., "Validating Fire Models: FPETOOL, CFAST, WPI/FIRE," Interflam '96, Cambridge, England, March, 1996.

OUTLINE OF A PERFORMANCE-BASED FIRE SAFETY DESIGN METHOD OF BUILDINGS IN JAPAN

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1. INTRODUCTION

It can be said that fire safety measures of buildings have been controlled, not only in Japan but also in any other country, basically by the detailed prescriptive standards stipulated in building or fire regulations. Traditionally, these standards have been developed by the discretion of so-called "fire experts". It should be duly recognized that the safety of buildings against fire have been remarkably improved thanks to such standards. As a result, fires are not considered as a major societal issue at least in most of the developed countries.

However, adverse effects have been also incurred. That is, the multiplication of such prescriptive rules have resulted the tremendous complexities in understanding of the meanings of the rules, the increase of fire protection cost, unnecessary restrictions on building designs and so forth. Such prescriptive standards are convenient in the sense that particular technical expertise is not needed for designers nor for building officials, but its serious disadvantage is that they resist to any incompliance however trivial it seems from the view point of safety, and thereby discourage the use of innovative materials, products, construction technologies and novel designs.

Recognizing such problems and also considering the significant progress achieved in the area of fire science and engineering, Building Research Institute (BRI), Ministry of Construction, Japan undertook a five-year project called "Development of Fire Safety Design Method of Buildings", 1982 through 1986. In this project, a performance-based fire safety design system was addressed. This system was favorably received among building industries and design firms, which may be proved by the remarkable increase of the fire safety designs applied for the approval by Minister of Construction after the end of the 5 year-project.

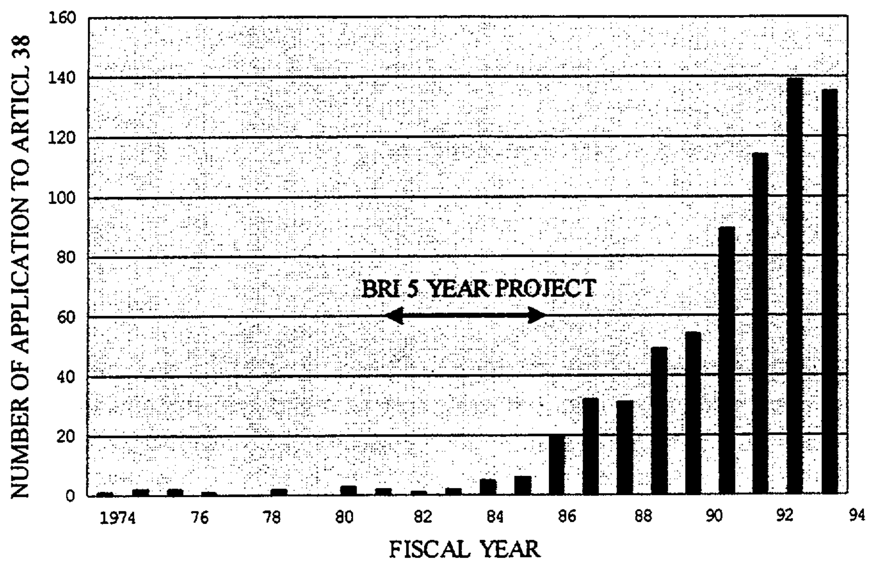

Figure 1 Number of Fire Safety Designs Applied for Article 38 of BSL

Unfortunately, however, the design system developed in this project was far from perfect. The most serious drawback is that the system can not yet be independent from the existing regulations, in other words, this can only be used for partially rationalizing the provisions in the Building Standards Law of Japan (BSL). Hence, efforts are still continued by BRI and by The fire safety design committee of Architectural Institute of Japan (AIJ) to improve the design system.

2. PURPOSE AND PHILOSOPHY

Precautions for fire safety in buildings have usually been established as mandatory rules by the authorities responsible for public safety, and enforced through administrative systems for building control. Most of the complaints and pressure from owners or builders of buildings associated with fire precautions arise in connection with the inflexibility of these mandatory regulations. There is no objection on the necessity to assure public safety. What is really needed is a design system which allows more flexibility while assuring the safety equivalent to the existing regulations.

In general, the requirements of a mandatory regulation are supposed to be restricted to what are absolutely indispensable for public safety and welfare since the abuse of mandatory rules may induce the danger of violations of basic human rights. The fire safety design method was intended to be a design system which can be used as an alternative to the existing BSL. Thus the design system should be equivalent to the Law. This means that the objectives and levels of safety of the design system must be basically the same as those required by the BSL, in other words the requirements in the design system are minimum.

On the other hand, the design method must be different in some respect from the BSL to allow more flexibility in building design. This is intended to be achieved by the objective-based structure of the design system and introduction of performance standards.

3. STRUCTURE OF THE DESIGN METHOD

A major part of the rigid nature of prescriptive provisions is caused by that they do not explicitly disclose what their purposes are, what scenarios of fire they assume and what level of safety they intend to be attain. What we had to do was to analyze the BSL, its related government orders, MOC orders and other related documents to identify what the prescriptive provisions mean. The objectives and the functional requirements for fire safety of buildings were thus identified. And the technical standards for verification of compliance were developed in view of equivalence to BSL provisions and flexibility.

3.1 Objectives

According to the analyses of BSL and the other related documents, the objectives of the fire safety provisions of BSL are considered to be as follows:

(1) Fire Safety of Individual Buildings
- (1.1) Prevention of Fire
- (1.2) Exclusion of Highly Hazardous Substance
- (1.3) Safety to Life
- (1.4) Prevention of Damage to Third Parties
- (1.5) Assurance of Fire Fighting Activity

(2) Mitigation of Urban Fire

3.2 Functional Requirements

The functional requirements are the description of the means specifically designated to each of the objectives to achieve their goals. Let's take an example of the functional requirements for objective (1.3) Safety to Life. Although essential means for life safety may depend on type of hazards, it has been considered as indispensable to provide buildings with adequate means of escape for the safety to life in case of fires. It can be said that the means to assure life safety are virtually specified only to assure safe evacuation. This common practice certainly has a good reason considering the nature of building and building fires.

A number of provisions can be found in the existing regulations regarding the assurance of safe evacuation, which may be interpreted and consolidated into the functional requirements of which items are as follows:

(1.3) Safety to Life
- (1.3.1) Evacuation planning
  - (1.3.1.1) Plans prepared in advance
  - (1.3.1.2) Plans include all potential occupants
  - (1.3.1.3) Plans consider all important building uses
  - (1.3.1.4) Plans are practicable
- (1.3.2) Restriction on the use of certain materials
- (1.3.3) Assurance of safe refuge
  - (1.3.3.1) Adequate refuge(s) provided

(1.3.3.2) Location of refuges
(1.3.3.3) Safety of refuges
(1.3.3.4) Appropriate condition for staying
(1.3.3.5) Alternate refuges depending on fire location
(1.3.4) Assurance of safe path of egress
(1.3.4.1) Assurance of at least one available path of egress
(1.3.4.2) Exits are clear and continuous
(1.3.4.3) Proper capacity and design for egress movements
(1.3.4.4) Exits are safe from dangers due to fire
(1.3.4.5) Special protection for unique circumstances

A definition is given to each of the requirements. These are the verbal manifestation of the principles for fire safety of buildings.

Likewise, functional requirements are given, together with their verbal definitions, to the other objectives. It is these principle statements that provides the grounds for physical provisions to be imposed, so they must be considered as the reflection of the agreement within the society of interest on the fire safety of buildings. It is vital for smooth operation of the design system that whatever is indispensable must be disclosed here and whatever provisions must not be imposed if not based on any of the requirements explicitly stated.

3.3 Technical Standards for Verification of Compliance

With only verbal statements, it is impossible to verify if a specific design of a building meet the requirements. It is necessary to provide each of the requirements with the technical standards which unequivocally indicate what are physically required for the building. These technical standards play important roles to determine the level of fire safety of buildings. There is no denying that the safety requirements, but this does not mean that the requirements are absolute. They are supposed to be more or less relative to the cost of fire protection, convenience of normal use etc. Perfect satisfaction of any of the requirements is virtually impossible, technically as well as economically. Therefore, some sort of compromise need be made. The technical standards can be understood as the technical expression of the society's compromise between the safety and the cost.

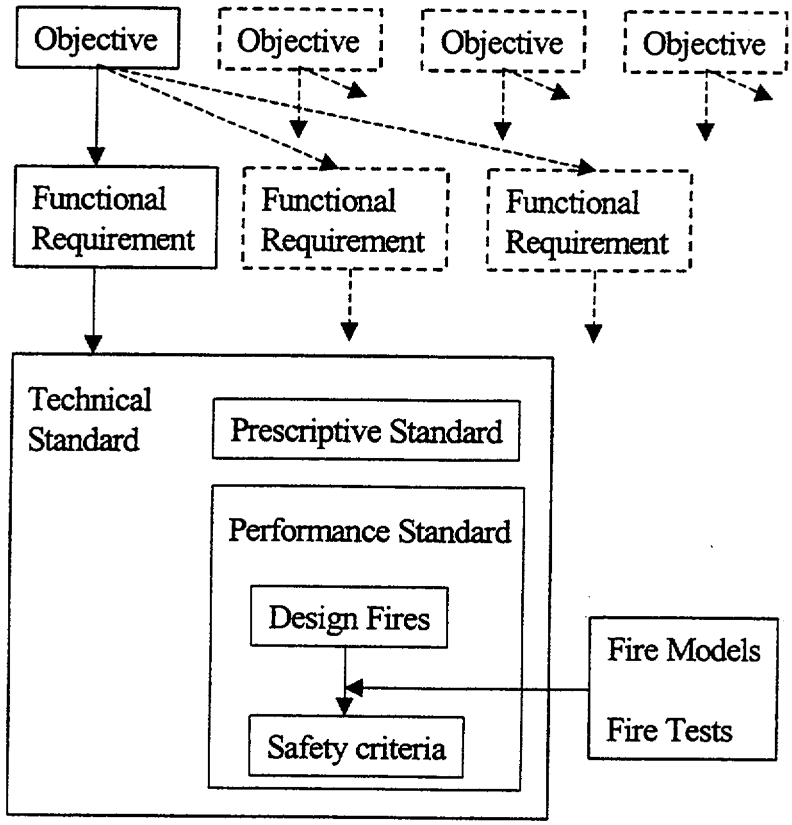

Figure 2 Structure of the Fire Safety Design Method

3.4 Performance Standards

In principle, the technical standards have to be given in terms of measurable or calculable values. In this sense, it can be said that both specification standards and performance standards are eligible as such unambiguous standards. However, specification standards inherently have the defects of stubbornness, so in view of flexibility it is desirable that as most as possible standards are performance standards, although at this moment it is, to some extent, inevitable to use other type of standards such as specification and deemed-to-satisfy.

The key elements of the performance standards consist of design fires, safety criteria and fire models. These respectively correspond to design load, allowable stress or strain and structural calculation methods in structural design system.

3.5 Design Procedure

The fire safety design procedure based on the performance standards will be basically the same for any requirement, which is illustrated in Figure 3, although specific standards and the relevant fire models are different depending on the specific requirement. This procedure is actually the procedure to verify the compliance of a design to the requirements. A building has to clear specified safety criteria under specified fire condition.

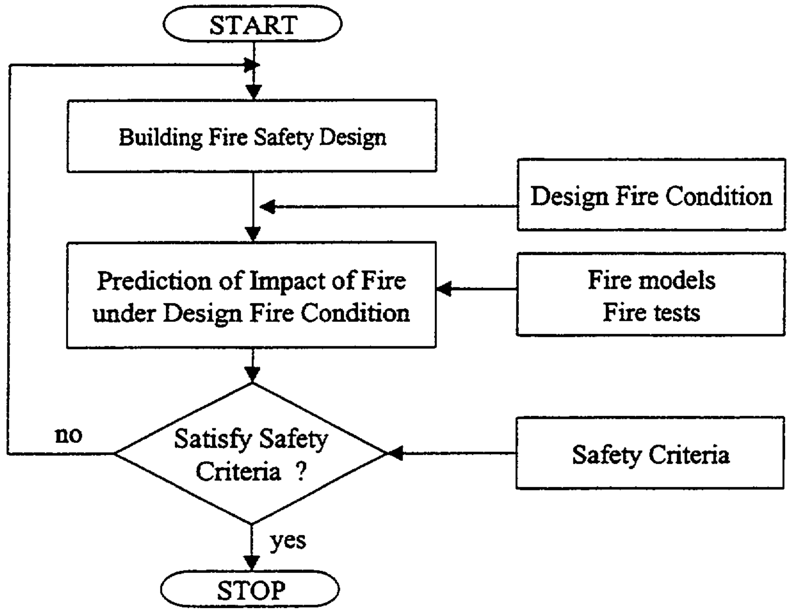

Figure 3 Fire Safety design Procedure Based on Performance Standards

4. CONSIDERATION ON SAFETY LEVEL

4.1 Acceptable Safety

It follows that the level of safety, in other words, the level of compliance to the requirements is determined by the combination of the corresponding design fires and safety criteria. Higher level of safety can be attained by imposing severer design fires and/or stricter safety criteria.

The design fire should include not only fire size but also pertinent scenarios: Even though the size of fire is the same, whether doors are open or not, for example, will make a significant difference in fire dynamics, hence safety to life, properties etc. What is important to stress is that probabilistic aspect of fire must be embodied in the design fire so that compliance verification can be performed with a minimum number of deterministic calculations. Otherwise, it will be practically impossible to operate a performance based design system.

The connotation of a design fire is illustrated in Figure 4, where the design fire is expressed by size of fire for simplicity. The solid line stands for a conceptual probability of fire incidences versus the size of fire. Statistically, like many other accidents, small size fires break out fairly frequently, but the larger the size of fires the less frequent their occurrence. The essential role of design fire is to require such fire safety measures that can cope with the hazards represented the design fire. The implicit premise is that the hazards which might be caused by fires smaller than the design fire are removed by the safety measures as a matter of course.

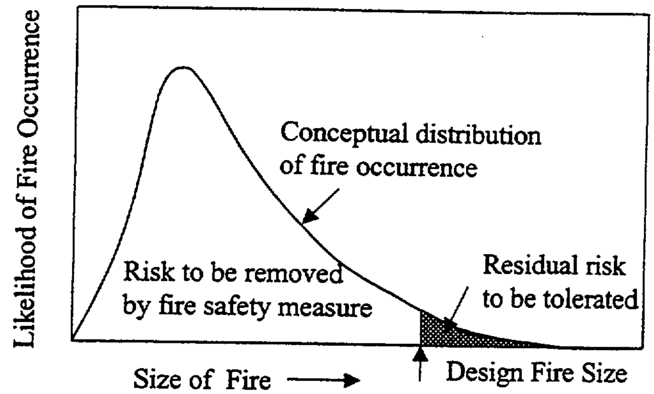

Figure 4 Connotation of Design Fire

4.2 Equivalence to Existing Code

Naturally, an extent of residual risk remains, in other words, we have to accept that the safety is no longer assured in the event a fire exceeding the design fire happen to break out. The residual risk and the expected loss due to fire may be decreased by setting a severe fire condition as the design fire. But it will in return result the increase of indirect loss such as cost of fire protection and inconvenience in normal use. Theoretically, the desirable design fire will be such that minimize the total of the expected direct and indirect losses. Practically, however, it is next to impossible to estimate the total cost. Also, in reality, safety cost in general tend to be determined based on the risk perceived by people rather than the risk actually exists. On the other hand, people in the countries where fire loss is stable tend to accept both the fire loss and the cost for fire safety measures which are controlled by the current regulations. In fact, nothing is more legitimate as the expression of societal agreements on acceptable fire risk and cost than the existing regulations in the countries. Therefore, the design fires should be so determined that the level of safety attained by the existing fire safety regulations can be reproduced by the fire safety designs based on the performance standards. Note, however, this does not mean that the same prescriptions as the existing provisions be retained but means the same level of fire safety performance be assured.

4.3 Consistency of level of safety

Accepting a certain degree of residual risk implies that we have the expected loss by fire during the life time of a building E given by

$$E = P_{fire} p_{fail} L_{damage} Y_{life} \qquad (1)$$

where P_{fire} is the probability of fire occurrence in the building per year, p_{fail} is the probability that the safety measure fails in the fire, L_{damage} is the loss caused by fire when the safety measure fails and Y_{life} is the life year of the building.

As an example of application of this concept, let's consider required fire resistance of a structural element on a floor of a multi-story building. For simplicity, we assume that the floors upper than the fire floor must be abandoned when the structural member collapsed by the fire broken out on the floor. In this case, only the fully developed (flashed over) fires become issue, so we can normally expect that

$$P_{fire} = p''_f A_{FLR}, \quad p_{fail} = p_{FO} p_{yield}, \quad L_{damage} = NA_{FLR} \qquad (2)$$

where p''_f is fire occurrence probability per unit floor area, A_{FLR} is the floor area, which is assumed to be the same on any floor for simplicity, p_{FO} is the flashover probability, p_{yield} is the probability that the structural member yields by the fire exposure, N is the number of floors above the fire floor.

Analyzing the provisions in the existing regulations, it is probably true that the regulations stand on the premise, although implicitly, that the expected loss of fire should be the same for a building with any height or size. That is, if considering two different buildings here it follows from Eqn.(1) and (2) that

$$p''_f p_{FO} N A_{FLR}^2 Y_{life} p_{yield} = \overline{p''_f}\, \overline{p}_{FO}\, \overline{N}\, \overline{A}_{FLR}^2\, \overline{Y}_{life}\, \overline{p}_{yield} \qquad (3)$$

or

$$p_{yield} = \left(\frac{\overline{p''_f}}{p''_f}\right)\left(\frac{\overline{p}_{FO}}{p_{FO}}\right)\left(\frac{\overline{N}}{N}\right)\left(\frac{\overline{A}_{FLR}}{A_{FLR}}\right)^2\left(\frac{\overline{Y}_{life}}{Y_{life}}\right)\overline{p}_{yield} \qquad (4)$$

This equation imply that the probability of yield of the structural members should be smaller for the building having occupancy with higher fire occurrence probability, more stories, larger floor area and longer life time. Incidentally, Canadian statistics indicate flashover probability is reduced to about 1/4 - 1/5, hence p_{yield} for sprinklered buildings can be 4 - 5 times larger than unsprinklered buildings.

Although the provisions on fire resistance in the current regulations seem to empirically reflect the relation of Eqn.(4), clearer recognition of this relationship will be beneficial for establishing a more consistent standards. The right hand side of Eqn.(3) may be considered to correspond to a reference conditions. Therefore, if we can identify the reference conditions of buildings with one hour fire rating, for example, and find $\overline{p}_{yield}$ for the case, then the allowable yield probability can be rationally determined. In addition, if some statistically-based fire load density distribution is available, the probability can be interpreted to the residual risk when a fire load density is prescribed as the design fire condition.

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Prepared by
Science Applications International Corporation
Los Altos, California

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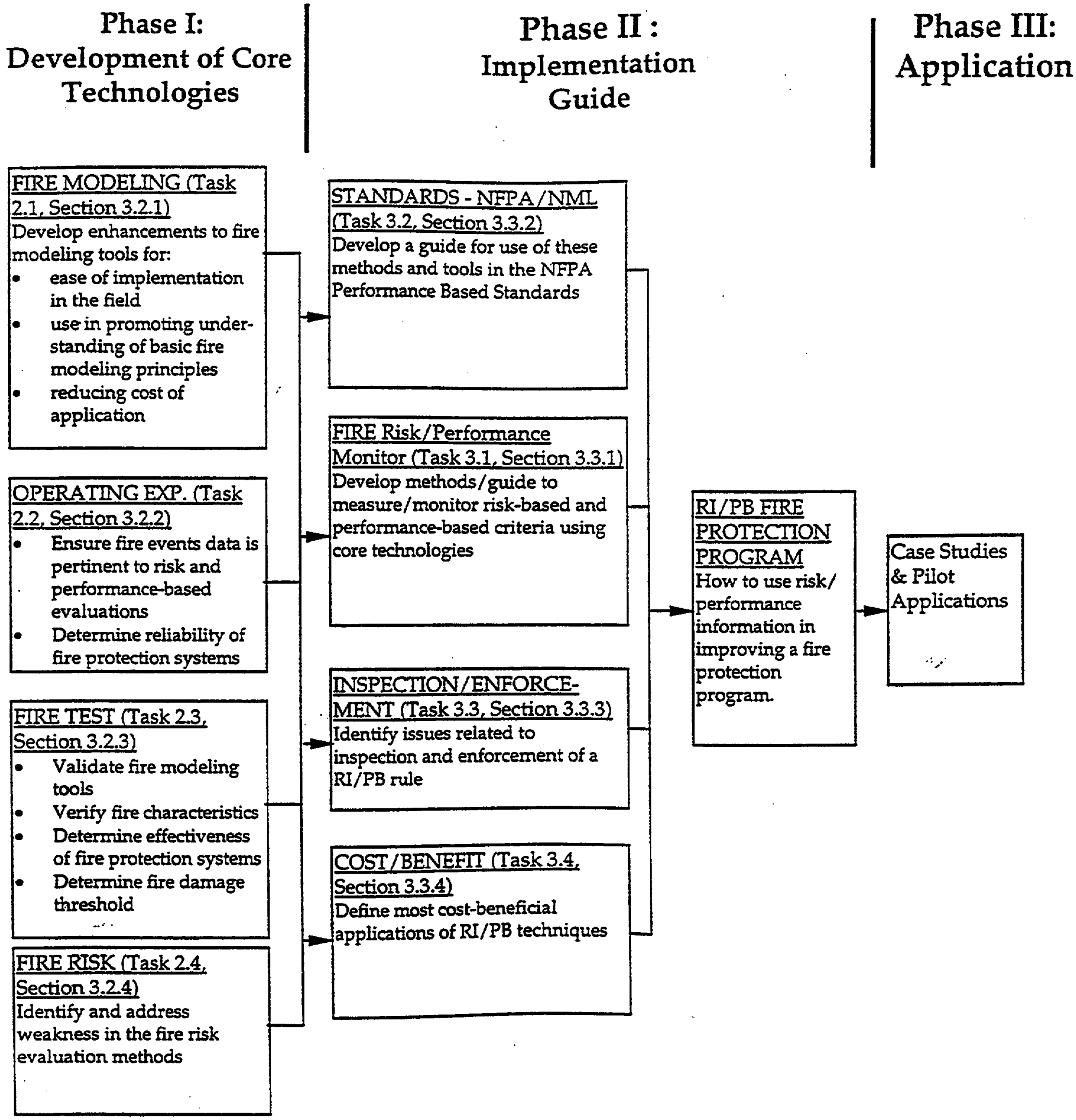
Figure 2-1. Task Flow Diagram for Risk-Informed/Performance-Based Fire Program



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Appendix F - Selecting Models or Other Analytical Methods*

A wide range of analytical tools is available to the.[1,2] In selecting a particular calculation method, it is important to evaluate its predictive capability. Guidance for evaluating the predictive capability of computer *fire models* can be found in ASTM E1355-92.[3] The process of model evaluation is important in determining the appropriate use, as well as the limitations, for a particular application. While a model may be appropriate for one *fire scenario*, it may be inappropriate for another.

Determining suitability for use also requires an evaluation of the sensitivity of the given model. Sensitivity analysis is a means of determining the effect of changes in individual input parameters on the results of a given model. The analysis may be carried out by holding all but one input variable constant and systematically studying the effects of that one variable on the predicted result.

If there is a high degree of *uncertainty* about the magnitude or variability of a given input variable for the design fire or the *fire scenario*, the model might be inappropriate if the output is particularly sensitive to that variable. On the other hand, if the given input has little affect on the output, then the tolerance for *uncertainty* is increased. In most cases, the most significant variable will be the heat release rate history input for the design fire. In some situations, however, heat losses to the compartment boundaries, specification of the physical properties of compartment boundaries, or the size of vent openings, may significantly affect the result.

A model's ability to accurately predict outcomes can be assessed by comparison with standard tests or large-scale compartment fire tests. In addition, documented fire experience from actual eyewitness accounts or behavior of materials in actual fires can also be used. Another means for evaluation would be comparison of model results with previously published data on full-scale tests where the specific output parameters being evaluated have been measured. Outcomes such as structural failure, increase of temperature and smoke, available escape time, or the response of detection systems may be used as benchmarks for comparing models to test results.

The process of model selection should also include a review of any limitations placed on the use of the model, either in the applications manual or the supporting technical literature.

General Guidelines for Modeling Analysis[4]

The procedures for conducting a modeling analysis for performance-based design will vary considerably, depending on the complexity of the analysis at hand. If the intent is to determine the size of the fire at the time of the sprinkler operation or the length of time required for that operation, for example, the analysis could be performed using the sprinkler-detector subroutine in FPEtool. On the other hand, if the *objective* is to determine the spacing of smoke detectors for a given *design fire scenario* that will allow a ten minute safe egress time from the

* Adapted from Custer, R. & Meacham, B. *Introduction to Performance-Based Fire Safety*, National Fire Protection Association, Quincy, MA: 1997.

building in the absence of automatic sprinklers, the analysis becomes more complex and may require dozens or even hundreds of computer runs.

One way to organize complex modeling tasks is to prepare an outline or plan indicating the modeling steps that need to be accomplished to arrive at an evaluation of a trial fire protection design for a given *design fire scenario*. Once the model or models of choice have been selected and documented, a *modeling matrix* can be developed. The modeling matrix is based on a list of the *fire scenario*s and design fires to be modeled, expressed as design fire and a group of trial fire protection designs to be evaluated. The variations included in the matrix would include presence or absence of specific fire protection systems and location of damage targets, such as occupants or property. Each damage *target* will be characterized by a performance criterion such as a minimum allowable exposure to heat, smoke, or corrosive agents. In addition, there may be multiple ventilation conditions, such as open and closed doors or HVAC systems on or off.

A full evaluation of a large modeling matrix for a particular design problem may take dozens of runs. To facilitate record keeping, a *naming convention* should be developed for the data files. The modeling process should be treated as a laboratory experiment in which variables are altered one at a time and a lab notebook is kept. The results should be reviewed as work progresses. Trends may be noted that can help focus the analysis. For example, if the performance criteria (untenable conditions) are reached prior to occupant escape time for small fires with a given detector spacing, it would be unnecessary to run larger fires unless a design involving reduced detector spacing or increased sensitivity is being evaluated.

Although each design situation is different, it is often useful to review published work for examples of how other fire protection engineers have used analysis and modeling tools. One place to look would be in the documentation for specific computer models. [5,6] Frequently, example runs are provided to assist users becoming familiar with the software. Studying the manner in which these runs were constructed can be a useful exercise. In addition, various articles have been written describing applications of modeling techniques to a variety of performance-based design problems.

Another source of examples of applications of computer modeling is in the field of fire reconstruction and failure analysis.[7,8,9] A number of studies of actual fires have employed methodologies that may be of use in understanding computer applications and applied to performance-based design.

Limitations of Modeling

There are a number of limitations on the use of correlations and models for the prediction of fire phenomenon[1]. The following is a brief overview of some of the restrictions or assumptions that limit the use of models. This is not intended to be exhaustive, and the reader is urged to review the technical documentation and references for models or correlations being used to determine what limitations may be present.

Room Geometry

Most *fire models* that deal with the prediction of ceiling layer thickness, ceiling jet velocity, or the operation of detection devices are based on the assumption of horizontal smooth ceilings. Thus, calculations with these programs would not model the effect, for example, of beams on the operation of sprinklers. The relative dimensions of compartments also are subject to some restrictions. For example, some models may not be appropriate for rooms with length-to-width ratios greater than 10:1 during early stages of fire growth, or for compartments where the height to minimum horizontal distance ratio exceeds one. As such, users are urged to exercise caution when evaluating fires in rooms larger than sizes that have been verified experimentally.[10] In addition, compartment layouts frequently have vent openings (doors and windows) on different wall surfaces. However, computer *fire models* generally treat the ventilation openings in a compartment as if they were one single opening and do not address any issues that might arise due to the specific location of the given opening.

Interior Finishes

In general, most compartment *fire models* consider the thermal characteristics of the bounding surfaces of the compartment for the purposes of energy balance calculations. At the present level of model sophistication, the combustible nature or fuel contribution, and flame spread effects of interior finish materials (such as walls, ceilings, and floors) are not included in the fire growth calculations unless they can be made a part of the overall heat release rate curve input by the modeler. However, some published works provide means for calculating flame spread on wall lining materials and for the resulting heat release rate in a compartment.[11,12,13]

Fire Suppression

Although the capability for predicting the effects of fire suppression activities or systems is not fully modeled by any of the programs currently in use, some programs, such as the fire simulator routine in FPEtool and the FASTLite, do provide limited capability for the evaluation of sprinkler systems. However, these programs only model the effect of a single sprinkler head operation on the heat release rate of the input *design fire curve*. Cooling effects on the hot gas layer and the effects of entrainment into the water spray are not included. Neither is the effect of pre-wetting of material not yet ignited lying within the spray envelope. Care should be taken in applying these sprinkler models when field experience would indicate that, due to the compartment geometry or the nature and geometry of the fuels involved, multiple sprinkler operation is expected.

The effects of non-water-based suppression systems, such as water mist, carbon dioxide, or other gaseous agents, are not modeled. In assessing the effectiveness of these suppression strategies for performance-based design, it is suggested that the engineer review the literature with respect to the performance of the candidate agent in actual fire suppression tests that are similar to the design situation being evaluated. In some instances, it may be valuable to arrange for testing to be conducted to obtain information to adequately model the performance of a system.

Accuracy of *Fire models*

The accuracy of a *fire model* may be assessed by its ability to predict the results of actual experimental data. Assessing models to determine their predictive capability is part of the process described earlier.

A number of published papers compare various *fire models* and experimental fire data.[14,15,16,17,18,19 20] When reviewing these papers, it is important to understand the implications of the stated outcomes to the specific project under evaluation.

For example, Deal and Beyler[18] compared measured and predicted temperature rises using a variety of different correlations. Their work indicated that some correlations over-predict temperature rise while others tend to under-predict. It is important to understand how variation between predicted and measured values affects the use of correlations and models for performance-based design or evaluation. If one were to select a correlation that over-predicted temperature, it might be said that this would be conservative and, in effect, provide a *safety factor*. Stated differently, using such a correlation would predict higher than actual temperatures at a given time. This could be interpreted to mean that in actual situation structural components would be subjected to less than predicted temperatures, as would unignited combustible materials or perhaps *building* occupants. If the correlation, however, is used to determine or predict when a sprinkler head or detector might operate, this would not be conservative, in that the prediction would have the fire protection system operating sooner than they would in the actual situation. On the other hand, under-predicting temperature, for example, would result in higher temperatures in any point in time, thus resulting in greater thermal stresses on structural elements, materials, or occupants within the exposed area.

Nelson and Deal reported on an approach for appraising expected performance of *fire models* by comparison with actual compartment fire data.[19] In their demonstration of this methodology, Nelson and Deal found that the four models tested provided what they felt were reasonable approximations for the tests being evaluated. Temperature of the upper layer, oxygen concentration, interface height, and flow of products out of a vent from the room were evaluated. The results, however, did indicate that some models tended to under-predict, while others over-predicted actual experimental data.

Other Limitations

Some of the other limitations on the applications of models include the fact that the calculations predict a uniform temperature throughout the hot layer, and changes in temperature occur instantaneously throughout the volume of the layer. In reality, there would be a thermal gradient vertically throughout the hot layer and horizontally as one goes further from the fire plume. In addition to uniform temperature distribution, it is assumed that smoke is also uniformly distributed.

References Cited

[1] Friedman, R., "An International Survey of Computer Models for Fire and Smoke," *Journal of Fire Protection Engineering*, Vol. 4, No. 3, Society of Fire Protection Engineers, Boston, MA, 1992, pp. 81-92.
[2] *Catalog of Computer Fire models*, Society of Fire Protection Engineers, Boston, MA, 1995.

[3] ASTM E1355-92, *Standard Guide for Evaluating Predictive Capability of Fire models*, American Society for Testing and Materials, Philadelphia, PA, 1992.
[4] Custer, R.L.P. and Meacham, B.J., "Introduction to Performance-Based Fire Safety," SFPE, 1997, pp. 154-156.
[5] Peacock, R.D., Jones, W.W., Bukowski, R.W., and Forney, C.L., *Technical Reference Guide for the HAZARD I Fire Hazard Assessment Method, Version 1.1*, National Institute of Standards and Technology, Gaithersburg, MD, June 1991.
[6] Portier, R.W., Peacock, R.D., and Reneke, P.A., *FastLite: Engineering Tools for Estimating Fire Growth and Smoke Transport*, Special Publication 899, National Institute of Standards and Technology, Gaithersburg, MD, April 1996.
[7] Nelson, H.E., *An Engineering Analysis of the Early Stages of Fire Development - The Fire at the DuPont Plaza Hotel and Casino - December 31, 1986*, NBSIR87-3560, National Institute of Standards and Technology, Gaithersburg, MD, 1987.
[8] Nelson, H.E., "Engineering Analysis of Fire Development in the Hospice of Southern Michigan," *Proceedings of the International Association for Fire Safety Science*, June 13 - 17, 1988, Tokyo, Japan, Hemisphere Publishing Corporation, New York, New York, 1989, pp. 927-938.
[9] Nelson, H.E., *Engineering View of the Fire of May 4, 1988 in the First Interstate Bank Building, Los Angeles, California*, NISTIR89-4061, National Institute of Standards and Technology, Gaithersburg, MD, 1985.
[10] Portier, R.W., Reneke, P.E., Jones, W.W., and Peacock, R.D., *A User's Guide for CFAST, Version 1.6*, NISTIR 4985, National Institute of Standards and Technology, Gaithersburg, MD, December 1992.
[11] Karlsson, B., "Models for Calculating Flame Spread on Wall Lining Materials and the Resulting Heat Release Rate in a Room," *Fire Safety Journal*, Vol. **23**, No. 4, 1994.
[12] Mittler, H. E., and Stekler, K. D., *A Model of Flame Spread on Vertical Surfaces,* National Institute of Standards and Technology, Gaithersburg, MD, NISTIR 5619, April 1995.
[13] Dembsey, N.A., and Williamson, R.B., "Coupling the Fire Behavior of Contents and Interior Finishes for Performance-Based Fire Codes Evaluation of a Fire Spread Model," *Journal of Fire Protection Engineering*, Vol. **8**, No. 3, Society of Fire Protection Engineers, Boston, MA, 1997.
[14] Dembsey, N.A., Pagni, P.J., and Williamson, R.B., "Compartment Fire Experimental Data: Comparison to Models," *Proceedings of the International Conference on Fire Research and Engineering*, 10-15 September 1995, Orlando, FL, Society of Fire Protection Engineers, Boston, MA, 1995, pp. 350-355.
[15] Wong, Doung, D.Q., "Accuracy of Computer Fire Models: Some Comparisons with Experimental Data with Australia," *Fire Safety Journal*, Vol. **16**, No. 6, 1990, pp. 415-431.
[16] Peacock, R.F., Davis, S., and Babrauskas, V., "Data for Room Fire Model Comparisons," *Journal of Research of the National Institute of Standards and Technology*, Vol. **96**, No. 4, pp. 411-462, Gaithersburg, MD, August 1991.
[17] Peacock, R.D., Jones, W.W., and Bukowski, R.W., "Verification of a Model of Fire and Smoke Transport," *Fire Safety Journal*, Vol. **21**, No. 2, 1993, pp. 89-129.
[18] Deal, S., and Beyler, C.L., "Correlating Pre-flashover Room Fire Temperatures," *Journal of Fire Protection Engineering*, Vol. **2**, No. 2, Society of Fire Protection Engineers, Boston, MA, 1990, pp. 33-48.
[19] Nelson, H.E., and Deal, S., "Comparing Compartment Fires with Compartment Fire Models," *Proceedings of the 3rd International Symposium of the International Association for Fire Safety Science*, Edinburgh, Scotland, 8-12 July 1991, pp. 719-728.
[20] *DETACT Evaluation Report*, Society of Fire Protection Engineers, Bethesda, MD, 1998.

Part I

CHAPTER 1
ADMINISTRATIVE PROVISIONS

SECTION 101
INTENT

101.1 Intent. To provide a level of health, safety and welfare, and to limit damage to property from events that are expected to impact buildings and structures.

Accordingly, this *code*, the Building Performance Code, intends buildings and structures to provide for.

1. An environment free of unreasonable risk of death and injury from fires.
2. A structure that will withstand loads associated with normal use, and of the severity associated with the location in which the structure is constructed.
3. Means of egress and access for normal and emergency circumstances.
4. Limited spread of fire both within the building and to adjacent properties.
5. Ventilation and sanitation facilities to maintain the health of the occupants.
6. Natural light, heating, cooking and other amenities necessary for the well being of the occupants.
7. Efficient use of energy.

SECTION 102
SCOPE

102.1 Scope. To achieve its intent, this *code* provides requirements for buildings and structures and includes provisions for structural strength, stability, sanitation, means of access and egress, light and ventilation, safety to life and protection of property from fire and, in general, to secure life and property from other hazards affecting the built environment. This *code* includes provisions for the use and occupancy of all buildings, structures, facilities and premises, their alteration, repair, maintenance, removal, demolition, and the installation and maintenance of all amenities including, but not limited to, such services as the electrical, gas, mechanical, plumbing, energy conservation and building transportation systems.

SECTION 103
ADMINISTRATION

103.1 Objective. To provide for compliance with this *code.*

103.2 Functional statement

103.2.1 *Architects* and *engineers* and all of the design team members shall possess the knowledge, skills and abilities necessary to demonstrate compliance with this code.

103.2.2 *Construction documents* shall be prepared in adequate detail and submitted for review and acceptance.

103.2.3 *Construction documents* shall be reviewed for compliance with the appropriate *code* provisions.

103.2.4 Construction shall comply with approved *construction documents* submitted in accordance with this code and verified by inspection or other means to demonstrate compliance with this code.

103.3 Performance Requirements

103.3.1 Building Owners Responsibility

103.3.1.1 The owner shall be responsible for retaining and furnishing the services of an *architect* or *engineer* in charge of the overall preparation of the *construction documents*, selecting a design team leader, and shall also be responsible for retaining the services of a design team which meets the qualifications as stated in Appendix D.

103.3.1.2 The owner shall be responsible for retaining and furnishing the services of an *architect* or *engineer* or recognized expert, who will perform as a peer reviewer, when required and approved by the code official. See Section 103.3.5.4 of this *code.*

103.3.1.3 The owner is responsible to operate and maintain a building or structure designed and built under this code in accordance with the *bounding conditions* and the maintenance and operations manual.

103.3.2 Qualifications of *architects* and *engineers*. *Architects* and *engineers* shall be responsible and accountable to possess the required knowledge and skills and include competent professionals with the knowledge and skills to perform design, analysis and test solutions in accordance with the provisions of this *code* and applicable professional standards of practice. Appendix D provides basic steps to assess the qualifications of a *architects* and *engineers*, design team members and reviewers.

103.3.3 *Architect, Engineer* and Design Team Responsibilities

103.3.3.1 The *architect, engineer* and the design team are responsible to apply the performance requirements and acceptance methods and approach for *performance-based designs* when using this *code.* This *code* requires design analysis and support documentation to demonstrate the design approach and to verify design objectives and compliance with this *code.*

103.3.3.2 The *architect, engineer* and the design team have the responsibility to provide the appropriate system design analysis, research, computations and documentation to demonstrate compliance with applicable performance requirements of this *code* and applicable *prescriptive code* provisions.

103.3.3.3 The *architect, engineer* and the design team shall use *authoritative documents* or *design guides* to determine testing and verification methods for selecting building materials that are compatible with the building systems approach selected.

103.3.3.4 The *architect, engineer* and the design team are responsible to document applicable *design guides*, accepted standards or *authoritative documents*, for a *performance-based design* and demonstrate how these documents are utilized to substantiate design solutions to show compliance with the provisions of this *code*. The use of documents which are not accepted as *authoritative documents* or *design guides* will require substantiation with the code official to obtain acceptance (guidance is provided in the Commentary).

103.3.4 Initial Documentation and Design Submittal

103.3.4.1 All documents required for submittal in this *code*, and other applicable codes under the jurisdiction of the code official, shall be submitted to the code official for review.

103.3.4.2 All *construction documents* shall be coordinated by a design team leader for consistency and compatibility and shall include documentation to demonstrate compliance with the performance provisions, including *acceptable methods*.

103.3.4.3 The *construction documents* shall clearly indicate those areas of the design that are performance-based and the applicable data to verify compliance with the performance provisions.

103.3.4.4 The *construction documents* shall specify when and where special inspection and testing are required, the standards of acceptance for demonstrating compliance with the *construction documents* and maintenance and operational requirements for future use of the building.

103.3.4.5 The *construction documents* shall include an evaluation of hazards and proposed resolution of associated risks with construction and phased or partial occupancy where applicable.

103.3.4.6 The design team's documentation for the project shall identify the goals and objectives; the steps undertaken in the analytical analysis; the facility maintenance and testing requirements; and limitations and restrictions on the use of the facility in order to stay within *bounding conditions*. Additional requirements for documentation may be specified in *engineers* and/or *design guides*.

103.3.4.7 The level of documentation provided shall be adequate to clearly convey the required information to the involved parties, and shall be commensurate with the scope and complexity of the project.

103.3.4.8 Design features, with *bounding conditions* that require continued maintenance or supervision by the owner throughout the life of the building, facility or process as conditions of compliance with the objectives of this *code*, shall be recorded as a deed restriction until released by the code official. Changes to the design documentation, where a new evaluation is required, shall be filed with the code official

103.3.4.9 When required by the code official, project documentation shall include a Design Concept Report, *Performance-based design* Report, and Operations and Maintenance Manual.

103.3.4.9.1 The Design Concept Report is intended to document the preliminary details of the project, identify the parties involved in the projects, and define the goals and objectives to be utilized in the *performance-based design* analysis. The Design Concept Report shall address general project information, project scope, description of building and occupant characteristics, project goals and objectives, selected event scenarios, methods of evaluation and documentation of project participants and their qualifications.

103.3.4.9.2 The *Performance-based design* Report is intended to document the steps taken in the analytical analysis, clearly identifying the criteria, parameters, inputs, assumptions, and limitations involved in the analysis. The report shall also document the design features proposed based upon the analysis and address the project scope, goals and objectives, performance criteria, magnitude of design loads and scenarios, final design, evaluation, critical design assumptions and *bounding conditions*, critical design features and *bounding conditions*, commissioning testing requirements, supporting documents and references.

103.3.4.9.3 An Operations and Maintenance Manual is intended to identify system and component commissioning requirements, and the required interactions between these systems. The manual shall identify for the facility owner and/or the facility operator those actions that need to be performed on a regular basis to ensure that the components of the *performance-based design* are in place and operating properly. Furthermore, the Operations and Maintenance Manual shall identify the restrictions or limitations placed upon the use and operation of the facility in order to stay within the *bounding conditions* of the *performance-based design*. The Manual shall address the following: description of critical systems, description of required system interactions, operation responsibilities, staff training, periodic maintenance and testing requirements, and limitations on facility operations due to *bounding conditions*.

103.3.5 Review and Approval

103.3.5.1 The code official shall be responsible to perform a knowledgeable review of the proposed design to verify compliance with this *code* or shall retain competent assistance to perform the review in accordance with acceptable standards of practice.

103.3.5.2 The code official shall be provided with sufficient documentation to support the validity, accuracy, relevance, and precision of the proposed methods. Copies of referenced documentation (reports, manuals, books, etc.) shall be made available to the code official.

103.3.5.3 Construction document review and approval shall be accomplished in accordance with the code official's procedures.

103.3.5.4 Review may be accomplished by a contract reviewer when assigned by the code official. In addition, the code official may require a *peer review* process to review design criteria and supporting documents and/or *construction documents.*

103.3.5.5 After *construction documents* and other supporting data are reviewed and approved by the code official to verify compliance with the applicable codes, construction permits may be issued.

103.3.6 Construction Approval

103.3.6.1 Prior to the start of inspection, a construction permit shall be obtained in accordance with the building and applicable codes.

103.3.6.2 Approved inspections shall be obtained in accordance with the building and applicable codes to continue construction activities.

103.3.6.3 Inspection, testing and related verification reports shall be filed with the code official to verify compliance with approved *construction documents* and applicable *prescriptive code* provisions.

103.3.6.4 The code official may require an approved third party *quality assurance* inspection and testing procedure where continuous or complex inspection procedures are necessary to verify that construction complies with the applicable codes and provisions of the approved *construction documents.*

103.3.6.5 Compliance shall be verified for materials, fabrication, manufacturer's and *engineer*'s installation procedures by product labeling, certification, *quality assurance* processes and testing, as applicable, to verify construction compliance.

103.3.6.6 At the completion of construction, the code official shall verify that inspection and testing reports demonstrate compliance with the applicable codes and approved *construction documents.*

103.3.7 Certificate of Occupancy

103.3.7.1 Prior to occupancy of a building, a Certificate of Occupancy shall be obtained from the code official.

103.3.7.2 A Certificate of Occupancy is required for the continuance of occupancy throughout the life of a building.

103.3.7.3 Failure of the building owner to demonstrate to the code official that the building is being operated and maintained in compliance with Section 103.3.1.3 is cause to revoke the Certificate of Occupancy or to not renew a conditional Certificate of Occupancy.

103.3.7.4 The code official may issue a Temporary Certificate of Occupancy for a limited time with specified conditions providing all life safety items are accepted.

103.3.7.5 The code official may issue a Conditional Certificate of Occupancy valid for a specified time period which requires continued compliance with *bounding conditions* and the maintenance and operations manual. Failure to maintain compliance with the conditions of the Conditional Certificate of Occupancy is a violation of this *code.*

103.3.8 Project Documentation

103.3.8.1 Documentation shall be prepared which verifies that all applicable performance and applicable *prescriptive code* provisions have been met.

103.3.8.2 All approved *construction documents*, the maintenance and operations manual, inspection and testing records, and certificates of occupancy with conditions shall be part of the project documentation as part of the code officials records.

103.3.8.3 Design features with *bounding conditions*, which are determined by the *architect* or *engineer* to require continued operation and maintenance by the owner throughout the life of the building as conditions of compliance with the objectives of this *code*, shall be recorded as a deed restriction as required by the code official until released by the code official.

103.3.9 Maintenance of the building

103.3.9.1 The building owner is responsible for maintaining the building in accordance with the approved *construction documents* when approved as a fully or partial *performance-based design* project. For a remodel, renovation, addition or change in use, reference Section 103.3.10.

103.3.9.2 Compliance with the Maintenance and Operation Manual and *bounding conditions* shall be verified throughout the life of the building at a frequency determined by the approved *construction documents.*

103.3.9.3 Documents verifying that the building is in compliance with the approved *construction documents* and is maintained in a safe manner shall be filed with the code official at a frequency approved by the code official.

103.3.10 Remodeling, addition or change of building use

103.3.10.1 An *architect* or *engineer* shall evaluate the existing building and the applicable *construction documents* for the proposed remodel, renovation, addition or change in use when affected changes to the building were previously designed under a *performance-based design.*

103.3.10.2 The *architect* or *engineer* shall verify through a written report whether or not the proposed design change will result in an increase in hazard or risk in excess of the *bounding conditions* to the approved design or otherwise adversely impact the existing building or its occupants based on the prior approved documents and this *code*.

103.3.10.3 The *architect* or *engineer* shall prepare and submit complete documents as designated in Section 103.3.4.

103.3.10.4 When a proposed scope of work for a tenant remodel or related space will not impact the recorded bounding approved performance conditions, an individual authorized by state law to prepare the design may prepare *construction documents* for submittal. A written report shall be provided to the code official to verify the proposed work does not impact the *bounding conditions* and create an unsafe condition.

103.3.10.5 When a remodel, renovation, addition or change in use occurs that causes the building to be in noncompliance with the performance or *prescriptive codes*, the administrative provisions of the *International Building Code* or other applicable codes shall apply.

103.3.10.6 When an owner and the *architect* or *engineer* propose changes to the design objectives and *bounding conditions* of the existing building, a written report shall be prepared to specify the new design objectives and demonstrate that compliance with the current code is met.

103.3.11 Administration and Enforcement

103.3.11.1 Administrative provisions of the *International Building Code* shall supplement the performance provisions for *plan review*, permit issuance, inspection, Certificate of Occupancy and enforcement.

SECTION 104
ACCEPTABLE METHODS

104.1 Objective. The objective of this provision is to require the use of recognized *authoritative documents* and/or *design guides* for analysis, measurement of performance and determination of criteria that are used to evaluate success or failure, thereby demonstrating compliance with the performance requirements of this *code*. See Appendix C for chapter specific Acceptable Methods.

104.2 Functional statement

104.2.1 Design approaches shall utilize accepted standards, *authoritative documents* and *design guides*, to demonstrate that designs are based upon applicable and valid technical and scientific methodologies.

104.2.2 Means shall be stated in the *construction documents* which specify how the design will be verified, and how the construction with applicable systems will be measured, to verify successful compliance with the design objectives and this *code*.

104.2.3 Testing and inspection of materials and systems for the purpose of verifying conformance to this performance *code* and the approved *construction documents* shall be based upon applicable standards and *authoritative documents*.

104.3 Performance Requirements and Acceptance Method Approach

104.3.1 The *architect/engineer* shall utilize the *acceptable methods* discussed below and the *construction documents* shall contain the design approach, analysis, research, computation and criteria for acceptance which specify the applicable *design guides*, standards and *authoritative documents* necessary and utilized to demonstrate that design objectives are met.

104.3.2 *Construction documents* shall include design verification methods which are required to demonstrate compliance with design objectives, and applicable *authoritative documents* and accepted standards.

104.3.3 The criteria for acceptance of standards, *authoritative documents* and *design guides* is based upon acceptance by the consensus process of a recognized professional groups of peers who formally acknowledge acceptance of the documents by their organization. Appendix B provides a list of accepted standards, *authoritative documents* and *design guides* which meet the intent of this section.

104.3.4 Designs that propose to use documents which do not meet the criteria for accepted standards, *authoritative document* or *design guides* of this section may comply with the individually substantiated design method as a means of verifying compliance (see Commentary for explanation).

104.3.5 *Design guides*, professional standards of practice and *authoritative documents* are acceptable as design methods for *performance-based designs*.

104.3.6 *Design guides* which are used as support for design documentation and analysis for *performance-based designs* shall be specified by the design professional and reviewed by the code official for compliance with this *code*.

104.3.7 Accepted standards or *authoritative documents* used in evaluating the performance of building materials, products and systems may be accepted as methods to verify compliance for *performance-based designs*.

104.3.8 Accepted standards or *authoritative documents* used for testing, measurement or inspection may be used as accepted methods by approved agencies or code officials in verifying building materials, products and system performance demonstrate compliance with the *performance-based design* and this *code*.

104.3.9 *Prescriptive code* provisions of the International Code Council's Family of Codes shall be deemed to satisfy; therefore, are deemed to meet the intent of the performance *code*.

APPENDIX D

GUIDANCE FOR ASSESSING CHARACTERISTICS OF QUALIFICATIONS FOR DESIGN AND REVIEW OF PERFORMANCE-BASED DESIGNS

(This Appendix is meant as supporting information and is not intended to be adopted)

In order for anyone to assess and verify that all of the members of a design team have the knowledge and characteristics needed to execute or review a performance-based design, the following lists are provided. Utilizing this technique is designed specifically for performance-based projects and does not apply to prescriptive-based designs. It is important to understand that utilizing this technique relies heavily on the personal ethics of each individual and a more formal declaration of education, training and experience may be requested by the "authority having jurisdiction." These characteristics explain the level or expertise necessary to form a complete design team, but they are not a requirement for every member of the team.

Characteristics of a Design Team Leader for *Performance-based design:*

1. Registered *architect* or *engineer* by the state or jurisdiction.
2. Knowledge of all facets of the project and the underlying principles of the performance-based *code* and concepts.
3. Ability to perform in the role of point of contact and to coordinate activities between the design team members, owner and code official.
4. Ability to ensure all elements of submittal to code official are compatible, coordinated, logical, complete and comprehensive in documentation.

Characteristic of a Qualified *Architect/Engineer* for *Performance-based design*

1. Registered *engineer* or *architect*.
2. Knowledge of underlying principles of performance-based *code* and concepts.
3. Education, training and experience in performance-based engineering design.
4. Skill (competence) in risk and hazard assessment tools as a design method.
5. Awareness of personal limitation of skills and when to acquire services of others with required skills.
6. Ability to utilize performance-based *code* objectives and to demonstrate compliance through documentation of decision making and solutions.
7. High skill level in engineering disciplines needed in *performance-based designs* for structural, mechanical and fire protection systems.

Characteristics of Competent Reviewers for *Performance-based design:*

1. Registered individuals by a state or jurisdiction with authorized practice typically not applicable to *performance-based design* in accordance with this *code.*
2. Knowledge of underlying principles and concepts of performance-based *code* provisions.
3. Education in performance-based engineering principles.
4. Competence in risk and hazard assessment tools as a design method.
5. Ability to verify design documents, meet analysis and documentation requirements and to demonstrate that objectives are met.
6. High skill level in engineering disciplines needed in *performance-based designs* for structural, mechanical and fire protection systems.
7. Manager should have knowledge of limitation of staff skills and when to utilize or acquire skills of others with required skills.

Characteristics of other Design Professionals working on Design Team.

1. Registered individuals by a state or jurisdiction with authorized practice.
2. Knowledge of *prescriptive codes* provisions and use for area of practice.
3. Awareness of personal limitation of skills and have an understanding of when to acquire services of others with the required skills.

1 **SFPE's Computer Model Evaluation Activities**

Morgan J. Hurley, P.E.
Technical Director
Society of Fire Protection Engineers

2 **Overview**

- Why evaluate fire models?
- The SFPE Task Group on Computer Model Evaluation
- Evaluation of DETACT-QS
- Lessons Learned

3 **Why Evaluate Fire Models?**

- Provide guidance on the confidence that a modeler can have in model output given their confidence in input

4 **Why DETACT-QS Was Selected**

- Relatively simple
- Limited scope of application
- Widely used

5 **Evaluation Approach**

- Follow ASTM E-1355
- Develop an evaluation report to supplement the model's documentation that:
  - Demonstrates the capabilities and limitations of the model
  - Highlights underlying assumptions

6 **Evaluation Format**

7 **Introduction**

- Describes the need, appropriate use and the purpose of the evaluation report
- Identifies limitations of evaluation

8 **Limitations of Evaluation**

- For use only by persons competent in the field of fire safety
- Supplement the informed judgement qualified users.
- Limited to the range of full-scale experiments used for comparison

9 **Model Description**

- Calculates the response time of thermally activated detectors and smoke detectors installed under large, horizontal, unobstructed ceilings for fires with user defined, time dependent heat release rates

10 **Evaluation Scenarios**

- "Unobstructed" (30 m x 30 m) ceilings in heights ranging from 3.0 m to 12 m
- 9.2 m x 5.6 m x 2.4 m (height) compartment

11 **Theoretical Basis of the Model**

- Calculates quasi-steady fire plume and ceiling jet temperatures and velocities based on the instantaneous heat release rate at each time step
- Uses a lumped mass, convection (only) heat transfer algorithm to predict detector

temperature

12 **Mathematical and Numerical Robustness**

- A "numerical test" (as defined in ASTM E-1355) was used
- Results of numerical test compared to DETACT-QS results

13 **Model Sensitivity**

- Sensitivity analysis used to investigate the relative change in output by varying an input parameter

14 **Evaluation Scenario Model Inputs**

- Three data sets used to evaluate DETACT-QS
  - Two series of full-scale tests conducted specifically for the evaluation
  - One set of previously published full-scale data

15 **Model Evaluation**

- Model predictions compared with experimental data
- Range of inputs where predictions yield "reasonable agreement" with the test data

16 **Summary**

- Summarizes key points from evaluation

17 **Lessons Learned**

- Need quality data
- Data analysis takes time

18 **Questions?**

Morgan J. Hurley, P.E.[1]

SFPE's Fire Model Evaluation Initiative: How ASTM Has Helped And Can Help

Reference: Hurley, M. J., "**SFPE's Fire Model Evaluation Initiative: How ASTM Has Helped And Can Help**," *ASTM's Role in Performance-Based Fire Codes and Standards, ASTM STP 1377*, J. R. Hall, Jr., Ed. American Society for Testing and Materials, West Conshohocken, PA, 1999.

Abstract: SFPE is nearing completion of its first computer model evaluation: DETACT-QS. DETACT-QS was chosen because of the model's simplicity, limited scope of application and widespread usage. The product of this review will be an evaluation report for use by users of the model, and reviewers of designs and submissions that are based on the model. The evaluation of DETACT was guided by the ASTM Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models (E 1355). This paper discusses the evaluation of DETACT in accordance with ASTM E1355, how ASTM has facilitated this effort, and identifies areas where ASTM could assist with future evaluation efforts.

Keywords: Computer fire models, model evaluation.

Introduction

The 1991 Conference on Firesafety Design in the 21st Century set the following national goal: "By the year 2000, the first generation of an entirely new concept in performance-based building codes be made available to engineers, architects and authorities having jurisdiction … in a credible and usable form." [1] Five strategies were identified for achieving this goal, one of which was "The usefulness, assumptions and limitations of engineering tools used … must be critically reviewed and documented by an independent and respected group of skilled engineering experts." [1]

In June of 1995, the Society of Fire Protection Engineers formed a task group to evaluate the scope, applications and limitations of computer models intended for use in the engineering evaluation and design of fire and life safety measures. The task group is composed of volunteer members from the United States, Canada, and New Zealand. Task group members come from academia, code enforcement, consulting, and research.

The task group's first objective was to identify an evaluation methodology and select a model to use as a test case. DETACT-QS was selected based on its simplicity, limited scope of application and widespread usage. DETACT-QS is a model for predicting the response of detectors to an arbitrary heat release rate history [2].

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After examining several approaches to evaluating computer models, the Task Group decided to follow E-1355. The guide "provides a methodology for evaluating the predictive capabilities of a fire model for a specific use." Specifically the method addresses four areas of evaluation: 1) model definition and evaluation scenarios, 2) verification of theoretical basis and assumptions used in the model, 3) verification of the mathematical and numerical robustness of the model, and 4) quantification of the uncertainty and accuracy of the model predictions.

The resulting evaluation report is intended to supplement the model's user's guide by demonstrating the capabilities and limitations of the model and highlighting underlying assumptions that are important for users to consider when applying the model.

Evaluation

DETACT-QS versions 1.2 (SI units) and 1.3 (English units) were "evaluated" as defined in ASTM E-1355. The evaluation report follows ASTM E-1355 (applicable sections of ASTM E 1355 are indicated below in parentheses.) As of the writing of this paper, all of the sections indicated below are complete, except for the last four (Model Evaluation, Quantifying Model Evaluation, Summary of Analysis and List of Limitations/Guidelines). The evaluation is expected to be completed in early 1999. The evaluation report is organized as follows:

- Introduction
- Model Description (Section 7.1 of ASTM E-1355)
- Evaluation Scenarios (Section 7.2)
- Theoretical Basis for Model (Section 8)
- Mathematical Robustness (Section 9)
- Model Sensitivity (Section 10)
- Model Inputs
- Model Evaluation (Section 11)
- Quantifying Model Evaluation (Section 11.3.6)
- Summary of Analysis
- List of Limitations/Guidelines

Introduction

The introduction describes the need, appropriate use and the purpose of the evaluation report. The evaluation is intended for use only by persons competent in the field of fire safety and is intended only to supplement the informed judgement of the qualified user. While the purpose of the evaluation is to provide information on the technical features, theoretical basis, assumptions, limitations, sensitivities, and guidance on the use of DETACT-QS, the evaluation is limited to the range of full-scale experiments used for comparison.

Model Description

The model description is derived from the model's original documentation. DETACT-QS was developed to calculate the response time of thermally activated detectors and smoke detectors installed under large, horizontal, unobstructed ceilings for fires with user defined, time dependent heat release rate curves [2].

DETACT-QS consists of an empirically derived algorithm that predicts the maximum temperature and velocity of fire plumes and ceiling jets for a user-specified ceiling height and radial distance from the plume centerline. A lumped mass, convection heat transfer algorithm is used to predict the thermal detector activation time.

The model description section also includes definitions, minimum hardware and operating system requirements, assumptions inherent in the model, input data requirements, and a list of references.

Evaluation Scenarios

The evaluation was conducted for "unobstructed" (30 m x 30 m) ceilings in heights ranging from 3.0 m to 12 m and in a 9.2 m x 5.6 m x 2.4 m (height) compartment. The details of the scenarios used are described in the "Evaluation Scenario Model Inputs" section below.

Theoretical Basis for the Model

DETACT-QS calculates quasi-steady gas flow temperatures and velocities based on the energy release rate at each time step. The thermal element is considered to be a lumped mass, and radiative and conductive heat transfer into and from the element is ignored. A logic flowchart is provided in this section of the evaluation report to illustrate the algorithm used in DETACT-QS.

Mathematical and Numerical Robustness

The mathematical robustness of the model was evaluated by conducting a "numerical test" as defined in ASTM E 1355. The model's algorithm was programmed into a mathematical solver following the logic flow chart. The predictions of the model and the solutions derived using the mathematical solver were compared for level of agreement.

Model Sensitivity

The results of a sensitivity analysis are used to demonstrate the relative magnitude of change that can be expected by changing an input parameter. Some input parameter changes will result in small or insignificant changes in model predictions while others may result in large changes in the predicted values. A sensitivity analysis can be used to [ASTM E 1355]:

- Determine the dominant input variables
- Define an acceptable range for each input variable
- Quantify the sensitivity of output variables to input variables
- Inform users about the level of care to be taken in selecting input data

Individual input parameters were varied to determine the effect on output, with the resulting sensitivity expressed as a percentage change in output per percent change in input. Input values were individually varied +/- 10% for a detector actuation temperature of 74° C, radial distances of 0.4 m & 11 m, response time indexes of 28 $m^{1/2}$-$s^{1/2}$ & 83 $m^{1/2}$-$s^{1/2}$, an initial room temperature of 21° C, ceiling heights of 2.4 m & 12 m and slow, medium, fast and ultra-fast heat release rates. (Figure 1) illustrates the results of this analysis.

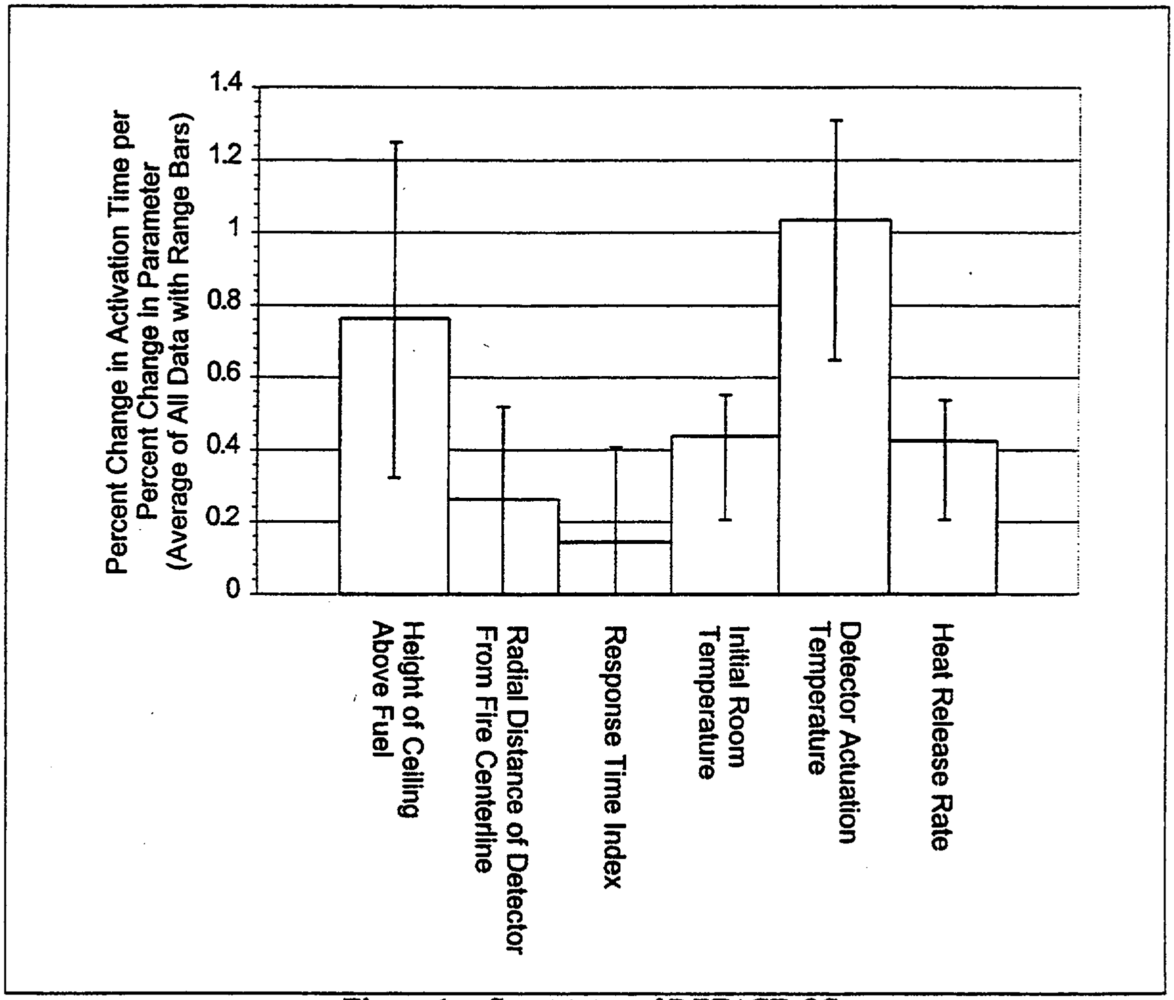

Figure 1 – *Sensitivity of DETACT-QS*

Evaluation Scenario Model Inputs

ASTM E 1355 identifies three possible sources of data to evaluate fire models: comparison with standard tests, comparison with full-scale tests conducted specifically for the evaluation, and comparison with previously published full-scale data. Three sets of full-scale test data will be used to evaluate DETACT-QS: one set of previously published data [3], and two sets of full scale data from tests conducted specifically for this evaluation [4, 5]. The previously published tests utilized a 9.2 m x 5.6 m x 2.4 m (height) compartment, 68° C sprinklers with an RTI of 55 $m^{1/2}$-$s^{1/2}$ and "slow," "medium" and "fast" growth fires as defined in NFPA 72 [6] with a maximum heat release rate of 1055 kW. The tests conducted specifically for the evaluation were under an "unobstructed" (30 m x 30 m) ceiling with heights ranging from 3.0 m to 12 m, "medium" and "ultra-ultra fast" ($\dot{q} = 1.7(t^2)$) fire growth rates with maximum heat release rates ranging from 847 kW to 10 MW, and disk thermocouples with RTI's of 32, 164 & 287 $m^{1/2}$-$s^{1/2}$.

Model Evaluation

These data sets will be evaluated using "specified calculations" as defined in ASTM E 1355. Initially, the task group planned to also conduct "blind calculations;" however, the data set that was planned for this evaluation was found to be unacceptable due to abnormalities in the conduct of the tests. The "blind calculations" did reveal a variety of treatments of fires that are located in corners or against walls, where the heat release rate is typically adjusted by a "location factor" [7]. However, the variety in treatments likely stems from the model's documentation not addressing these scenarios.

Quantifying the Model Evaluation

The model predictions will be examined to determine how well the model predicted results within a reasonable level of agreement to the actual test results. In this case, reasonable agreement is defined as predictions that are within the range of values, for a given scenario, provided by a limited series of replicate validation tests. For DETACT-QS the output parameters evaluated will be the detector actuation time, the fire plume and ceiling jet gas temperature and the detector temperature. One possible result of the evaluation may be a combination of geometries and heat release rates where model predictions yield "reasonable agreement" with the test data.

Summary

The summary section will contain a summary of the analysis and a list of limitations and guidelines for use of the model. This section of the evaluation is targeted at a wide audience to include qualified users as well as non-users who may need to evaluate building designs based on the output of the model.

How ASTM Has Helped

ASTM assisted this evaluation in a number of invaluable ways. Before the task group could evaluate a model, they needed to decide *how* to evaluate the model. It was extremely beneficial to have ANSI-approved procedures to follow instead of having to develop their own procedures.

Secondly, the 1992 version of ASTM E-1355 was not as extensive as the 1996 draft. ASTM provided a draft standard to SFPE for use by the task group during their evaluation. This facilitated the task group by providing more detail in how an evaluation should be conducted without having to wait until the next edition of ASTM E-1355 was published.

The ASTM Standard Guide on Documenting Computer Software for Fire Models (ASTM E 1472) defines minimum information that should be provided in a model's documentation. Although not used in this evaluation since DETACT-QS was written before publication of ASTM E 1472, this standard will be useful in evaluating the adequacy of documentation in future model evaluations.

The definition of a common set of terminology related to fire modeling, both in ASTM E 1355 and in the ASTM Terminology Related to Fire Standards (ASTM E 176) ensures that terminology is used in a consistent manner.

Additionally, the ASTM Standard Guide for Data for Fire Models (ASTM E1591) provides useful guidance to model users for determining applicable input data for specific model runs.

How ASTM Can Help

A standard on reporting of fire test data would be useful. During the evaluation, it was occasionally difficult to compare data from different test series. For example:

- Data would be reported graphically in some test series and numerically in others, where the scale of the graph made it difficult to accurately interpret data.
- Greater detail regarding test instrumentation would be helpful, particularly for items that are not standard "apparatuses" (e.g., thermocouples, sensors, etc.)

An ASTM standard on reporting of fire test data would alleviate these difficulties and ensure that data from different test series or from different labs could be considered on the same basis.

Summary

There will be increasing need for reliable calculation methods and data as fire protection engineering evolves from specification-based to performance-based. Organizations such as SFPE and ASTM can facilitate this evolution by activities such as those mentioned in this paper.

References

1 *Proceedings*, Conference on Firesafety Design in the 21st Century, May 8-10, Worcester Polytechnic Institute, Worcester, Massachusetts.

2 Evans, D.D., and Stroup, D.W., *A Method to Calculate the Response Time of Heat and Smoke Detectors Installed Below Large Unobstructed Ceilings*, *NBSIR 85-3167*, U.S. National Institute of Standards and Technology (formerly National Bureau of Standards), Gaithersburg, MD, 1985.

3 Vettori, R. *Effect of an Obstructed Ceiling on the Activation Time of a Residential Sprinkler, NISTIR 6253*, National Institutes of Standards and Technology, Gaithersburg, MD: 1998.

4 Sheppard, D. "Fire Environment Tests Under Flat Ceilings," Underwriters Laboratories, Northbrook, IL: 1997.

5 Sheppard, D. "Fire Environment Tests Under Flat Ceilings," Underwriters Laboratories, Northbrook, IL: 1998.

6 NFPA 72, *National Fire Alarm Code*, National Fire Protection Association, Quincy, MA: 1993.

7 Mowrer, F. & Williamson, R. "Estimating Room Temperatures from Fires Along Walls and in Corners," *Fire Technology*, Vol. 23, May 1987.

FRS PUBLICATIONS ON CFD FIRE MODELLING

1. Cox G and Markatos N C. 'Two and Three Dimensional Modelling of Fire in Enclosures'. Proc Workshop on Fire Modelling and Scaling. Naval Research Lab. Washington, 1981, p17-26

2. Markatos N C and Cox G. 'A Field Model for Smoke Flow in Enclosures'. Proc First Specialists Meeting (International) of the Combustion Institute, p 653-659, 1981

3. Markatos N C and Cox G. 'Turbulent Buoyant Heat Transfer in Enclosures Containing a Fire Source'. Proc Seventh International Heat Transfer Conf, Vol 6, p 373-379 (1982)

4. Markatos N C, Malin M R and Cox G. 'Mathematical Modelling of Buoyancy - Induced Smoke Flow in Enclosures'. Int J of Heat and Mass Transfer, 25, 63-75, (1982)

5. Markatos N C and Cox G. 'Reply to comments on above'. Int J of Heat and Mass Transfer, 25, 1777 (1982)

6. Cox G and Kumar S. 'Computer Modelling of Fire'. Building Research Establishment Information Paper, IP2/83 (1983), pp 4

7. Cox G and Kumar S. 'Computer Modelling Could Aid Designers at Early Stages'. Fire 76, 158-159 (1983)

8. Cox G. 'A Field Model of Fire and its Application to Nuclear Containment Problems'. Proc OECD Fire and Explosion Conference, Los Alamos Report, LA 9911C, p 199-210, CSNI Report No 83.

9. Kumar S and Cox G. 'The Application of a Numerical Field Model of Smoke Movement to the Physical Scaling of Compartment Fires'. 837-848 in Numerical Methods in Thermal Problems ed Lewis R W, Johnson J A and Smith W R, Pineridge Press, 1983

10. Cox G. 'Predicting Fire Spread in Buildings by Computer'. Post Maagazine and Insurance Monitor, March 1984, p 710-711.

11. Cox G. 'Computing Fire Spread'. Building, September 84, p 53.

12. Markataos N C and Cox G. 'Hydrodynamics and Heat Transfer in Enclosures Containing a Fire Source'. Physico Chemical Hydrodynamics Journal 5, 53-66 (1984)

13. Cox G and Kumar S. 'The Mathematical Modelling of Fire in Forced Ventilated Enclosures'.

14. Cox G and Kumar S, p 629-640 Proc. 18th DOE Nuclear Airborne Waste Management and Air Cleaning Conference, Harvard University, 1984

15. Cox G. Simulating Fires in Buildings by Computer - The State of the Art'. Proc 10th Intl Association of Forensic Sciences Meeting, Oxford, 1984 pp 23.

16. Cox G and Heselden A J M. 'Modelling Smoke Flow'. Letter to Fire Prevention, 168, 11 (1984)

17. Kumar S and Cox G. 'Mathematical Modelling of Fire in Road Tunnels'. p 61-76 in Proc 5th Intl Symposium on Aerodynamics and Ventilation of Vehicle Tunnels, BHRA, 1985

18. Cox G. 'The Mathematical Modelling of Fires in Enclosures'. Proc Interflam 85, Conference, Interscience, London, p 56-63 (1985).

19. Cox G. 'Fighting Fire in the Computer'. Spectrum-British Science News, 1985, No 191, p8-10.

20. Markatos N C, Pericleous K A and Cox G. 'A Novel Approach to the Field Modelling of Fire'. Physico Chemical Hydrodynamics Journal 7, 125-143 (1986)

21. Kumar S, Hoffman and Cox G. 'Some Validation of JASMINE for fires in Hospital Wards', p 159-169. Lecture Notes in Engineering No 18, Numerical Simulation of Fluid Flow and Heat Mass Transfer Processes, Springer, 1986

22. Cox G, Kumar S and Markatos N C. 'Some Field Model Validation Studies' p 159-171 in Fire Safety Science, Proc of the First International Symposium, Hemisphere, 1986

23. Kumar S, Cox G and Hoffman N. 'Mathematical Modelling of Fires in Hospital Wards' p 111, 5-11. 14th National Conference on Fluid Mechanics and Fluid Power, Roorkee, India 1986;

24. Cox G and Kumar S. 'Field Modelling of Fire in Forced Ventilated Enclosures'. Combustion Science and Technology, 5, 7-23, 1987

25. Kumar S and Cox G. 'Mathematical Modelling of Fire in Road tunnels - Validation of JASMINE'. Transport and Road Research Lab Contractor Report No 28, 1986 pp 87

26. Cox G. 'Computational Fire Dynamics'. Chartered Mechanical Engineer, July/August 1986, p 29-31.

27. Cox G and Kumar S. 'A Numerical Model of Fire in Road Tunnels'. Tunnels and Tunnelling, 19, 3, p 55-60, 1987

28. Cox G. 'Simulating Fires in Buildings by Computer - The State of the Art'. J Forensic Science Society 27, 175-188, 1987.

29. Moss J B, Cox G and Kumar S. 'Laminar Flamelet Models of Fire - the Prospect'. p 53

30. 'Fundamental Aspects of Polymer Flammability', Cox G and Stevens G (eds), Institute of Physics, 1987

31. Pericleous K A, Worthington D and Cox D. 'The Field Modelling of Fire in an Air Supported Structure' p 871-880. Proc Second International Symposium on Fire Safety Science, Hemisphere, 1989

32. Kumar S and Cox G. 'Radiation, Convection and Surface Roughness Effects in the Numerical Modelling of Fire', ibid p 851-860

33. Kumar S and Cox G. 'Radiant Heat and Surface Roughness Effects in the Numerical Modelling of Tunnel Fires' p 515-526. Proc 6th International Symposium on Aerodynamics and Ventilation of Vehicles Tunnels, BHRA, 1988

34. Kumar S and Gox G. 'Mathematical Modelling of Fire in Road Tunnels, Transport and Road Research'. Lab Contractor Report 101, 1988 pp 47

35. Cox G, Chitty R and Kumar S. 'Fire Modelling and the King's Cross Fire Investigation'. Fire Safety Journal 15, 103-106 (1989)

36. Cox G and Moss J B. 'Fire Science and Aircraft Safety'. AGARD/NATO Conference. Proceedings No 467, p 16, 1989, pp 12

37. Cox G, Kumar S, Cumber P, Thomson V and Porter A, 'Fire Simulation in the DesignEvaluation Process: An Exemplification of the use of a Computer Field Model', Proc Interflam 90 Conference, p 55-64, Interscience 1990

38. Kumar S, Gupta A K and Cox G. 'Effect of Thermal Radiation on the Fluid Dynamicsof Compartment Fires'. p 345-354 Proc Third International Symposium on Fire Safety Science, Elsevier, 1991

39. Fire Modelling, BRE Digest No 367, Building Research Establishment, 1991, pp 8.

40. Cox G, Cumber P, Lockwood F C, Papdopoulos and Taylor K, 'On the Field Modelling of Fire using Parallel Processors', to be published in Proc Eurotherm Seminar No 17, Heat Transfer in Radiating and Combusting Systems, October 1990, Springer, 1991 p 4

41. Cox G, Some Recent Progress in the Field Modelling of Fire, Proc First Asian Conference on Fire Science and Technology, pp 50-59, Intl Academic Pubs, Beijing, 1992.

42. Chitty R, Cox G, Fardell P J and Morris W A, Mathematical Fire Modelling and its Application to Fire Safety Design, BRE Report 223, Building Research Establishment 1992

43. Kumar S. 'Fire development and smoke spread in tunnel - some modelling considerations'. In Proc. 1st International Conference on the Safety in Road and Rail Tunnels, Basel, Switzerland, 1992, p 379.

44. Fardell P, Rowley J, Ellwood J, Kumar S and Vollam S. 'A study of life threat in bus fires'. p 401, Proc. INTERFLAM'93 Conference, Interscience, 1993,.

45. Cox G, and Rubini P A, Development of a New CFD Fire Simulation Model, Proc Nordic Fire Safety Eng Symposium, VTT Finland 1993.

46. Miles S, and Cox G, Modelling the Development of Fires in Warehouses pp 145-168, Industrial Fires ed S Cole & P J Wickes, CEC EUR 15340 EN, 1993.

47. Cox G, and Miles S, Modelling the Consequences of Fire in Warehouses, p 4.1-4.12, I Chem E Symposium Paper No. 3, 1993

48. Cox G, SOFIE 'A Model in the Making', Building Services, pp 31-33, November 1994.

49. Kumar S and Yehia M. 'Mathematical modelling of transient ceiling characteristics of fires', In Proc. 1st ISHMT-ASME Heat and Mass Transfer Conference and 12th National Heat and Mass Transfer Conference, Bhabha Atomic Research Centre, Bombay, India, 1994, p 771.

50. Miles S and Cox G, Transient CFD Model to Predict Fire Product Emissions from Warehouses, 2nd Intl Seminar on Industrial Fires, Cadarache, May 1994.

51. Miles C D, Cox G, Christolis M N, Christidou C A, Boudouvis A G & Markatos N C, Modelling the Environmental Consequences of Fires in Warehouses. Proc 4th Intl Symposium on Fire Safety Science pp 1221-1232, IAFSS, 1994.

52. Cox G, The Challenge of Fire Modelling, Fire Safety Journal, 23, 123-132, (1994)

53. Kumar S. 'Field model simulations of vehicle fires in a Channel Tunnel shuttle wagon', In Proc. 4th International Symposium on Fire Safety Science, Ottawa, Canada, 1994, p 995.

54. Kumar S and Yehia M. 'Application of JASMINE to the modelling of vehicle fires in a Channel Tunnel shuttle wagon', In Proc. 2nd International Conference on the Safety in Road and Rail Tunnels, Granada, Spain 1995, p 321.

55. Kumar S, Heywood G M and Liew S K. 'JASMINE sprinkler model - Some validation studies', In Proc. 1st European Symposium on Fire Safety Science, Zurich, Switzerland, 1995, p 79.

56. Kumar S. 'The use of computer modelling in the design of smoke control systems in buildings'. Building Serv. Eng. Res. Technol., 16, (4), B41-B54, 1995.

57. Kumar S and Yehia M. 'CFD modelling of vehicle fires in a Channel Tunnel wagon'. In Proc. 1995 European PHOENICS Conference, Trento, Italy, 1995, Paper 16.

58. Cox G, Chapter 1, Basic Considerations, pp 1-30, Combustion Fundamentals of Fire, Academic Press, 1995.

59. Cox G, Chapter 6, Compartment Fire Modelling, pp 332-404, Combustion Fundamentals of Fire, Academic Press 1995.

60. Cox G, Computational Fluid Dynamics and the Modelling of Fire, Proc 1st Intl Seminar on Fire and Explosion Hazards of Substances and Venting of Deflagrations, pp88-102, All Russian Research Inst for Fire Protection, Moscow, 1995

61. Bresloff N, Rubini P and Cox G, CFD Modelling of a Fire Resistance Furnace, First European Symposium on Fire Safety Science, Zurich, 1995

62. Miles S & Cox G, Prediction of Fire Hazards Associated with Chemical Warehouses, ibid

63. Cox G. Computational Fluid Dynamics and the Modelling of Fire. Proceedings of the First International Seminar on Fire and Explosion Hazards, pp 88-102, All-Russian Research Institute for Fire Protection, 1995

64. Miles, S.D and Cox G. Transient Computational Fluid Dynamics Model to Predict Fire Product Emissions from Warehouses, Proceedings of Industrial Fires II Workshop, European Commission EUR 15967, 1995

65. Cox G, Relationships for Smoke Control Calculations, CIBSE Technical Memoranda TM19:1995, Chartered Institution of Building Services Engineers, London, 1995

66. Miles S D and Cox G. Prediction of Fire Hazards associated with Chemical Warehouses, Fire Safety Journal, 27, pp. 265-287, 1996

67. Cox G, Kumar S, Blackmore P, Osmond S and Smith M. Modelling Building Performance and Safety using CFD, BRE Client Report CR133/96, July 1996

68. Cox G, Curtat M, di Blasi C and Kokkala M, Reaction to Fire of Construction Products-Area B: Fire Modelling, European Commission DGXII, EUR 16959, 1996

69. Miles S D and Kumar S. 'CFD modelling of fires in the Memorial tunnel', TRL Contract Report, TCR 142/96, Building Research Establishment, 1996.

70. Kumar S, Heywood G M and Liew S K. 'Superdrop modelling of a sprinkler spray in a two-phase CFE-particle tracking model', In Proc. 5th International Symposium on Fire Safety Science, Melbourne, Australia 1997, p 889.

71. Cox G, CIBSE Guide E, Fire Engineering, Appendix 9.A1: Fire Modelling using CFD, Chartered Institution of Building Services Engineers, London, 1997

72. Kumar S. 'Computer love', Fire Prevention, 302, 46, 1997

73. Miles S, Kumar S and Cox G. The Balcony Spill Plume - some CFD Simulations, Proc. 5th International Symposium on Fire Safety Science, Melbourne, pp 237-247, IAFSS, 1997

74. Kumar S and Chitty R. 'Predicting thermal conditions in a steel compartment adjacent to a fire in an off-shore structure', In Proc. Symposium on Computational and Experimental Methods in Mechanical and Thermal Engineering, On the occasion of 100th Anniversary of the Laboratory of Machines and Machine Construction, Department of Mechanical and Thermal Engineering, University of Gent, Gent, Belgium,1998, p 213.

75. Kumar S. 'Role of CFD modelling in Fire Safety Engineering', In Proc. 1st Eurofire Conference, Brussels, Institution of Fire Engineers-Belgian Branch, 1998.

76. Chitty R and Kumar S. 'Development of an integrated fire modelling environment for the study of smoke-egress interactions', In Proc. 1st Int. Conf. on Human Behāviour in Fire, Ulster, UK, 1998, p 649.

77. Cox G. Turbulent Closure and the Modelling of Fire using Computational Fluid Dynamics, Phil Trans Roy Soc, London A356, 2835-2854, 1998

78. Welch S and Pchelintsev A, Numerical Predictions of Heat Transfer to a Steel Beam in a Fire, pp299-313, Proceedings of the Second International Seminar on Fire and Explosion Hazards, pp 299-313, All-Russian Research Institute for Fire Protection, Moscow, 1998

79. Miles, S.D Kumar S and Cox G, Comparisons of 'blind predictions' of a CFD model with experimental data, Proc 6th International Symposium on Fire Safety Science, Poitiers 1999-*to be published*

80. Kumar S and Chitty R. 'CFD Study of thermal detection in a closed compartment subject to external fires', 6th International Symposium on Fire Safety Science, Poitiers, France, 1999-*to be published*

81. Holborn P G, Nolan P F and Kumar S. 'A Meandrop method for the characterisation of a sprinkler spray in a two-phase CFD-particle tracking model- An improved alternative to the superdrop method', 6th International Symposium on Fire Safety Science, Poitiers, France, 1999-*to be published*

82. Kumar S. 'The development of best practice procedures for the CFD modelling for fire safety design in buildings', Building Serv. Eng. Res. Technol. 1999-*to be published*

83. Miles S, Kumar S and Andrews R. 'Validation of a CFD model for fires in the Memorial Tunnel', 1st International Conference on Tunnel Fires and Escape from Tunnels, Lyon, France 1999-*to be published.*

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11. ABSTRACT *(200 words or less)*

The U.S. Nuclear Regulatory Commission (U.S. NRC) convened a planning meeting with international experts and practitioners of fire models to discuss a potential international collaborative project to evaluate fire models for nuclear power plant applications. The meeting was jointly organized with the Society of Fire Protection Engineers and the University of Maryland and was held at the University of Maryland on October 25 - 26, 1999. Thirty representatives from eight national organizations in the United States and six international organizations from five countries attended the planning meeting. The attendees represented organizations in the nuclear industry and built environment in several countries that are involved in the development and use of fire models.

All organizations represented responded positively to NRC's invitation for a collaborative effort. Representatives indicated they intended to participate and contribute to the project with the goal of obtaining results of mutual benefit to their respective organizations. Participants plan to contribute through a variety of means. The core of the work will be conducted by six nuclear organizations in France, Germany, Finland, and the United States. The initial effort will consist of analyzing a specific issue, safe separation distance between redundant trains in nuclear power plants, to evaluate how current state-of-the-art fire models can be used to support decision making regarding this issue in nuclear power plants. A guidance/reference document oriented toward "low end" users on the use of current fire models will be the initial product of the project. After several issues are evaluated and the current state of the art of fire models better defined, a second phase of the project could be initiated to improve fire modeling and tools in order to support their extended use for fire safety design and decision making in nuclear power plants.

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